



Improving the stability of oriented strand board manufactured from mountain pine beetle wood

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Abstract

Oriented strand board (OSB) accounts for a large share of the market for sheathing and sub-floor underlay, but because of its lower dimensional stability when exposed to moisture, it has not completely replaced plywood. The manufacture of OSB represents one of the major ways in which value can be recovered from mountain pine beetle-killed wood. Large amounts of beetle-killed wood are being processed into OSB in western Canada. The main challenges associated with using this wood for oriented strand board are log dryness, greater brittleness, and the wood's propensity to break up into smaller fragments during the production of board strands, which reduces the composite's moisture resistance and dimensional stability. Log rehydration and modification of pressing schedules for OSB have enabled beetle-killed wood to be used in commodity-board production, but need remains to develop practical solutions to the problem of high water absorption and thickness swelling of boards.

This project investigated a range of different coating and water-repellent technologies to reduce moisture absorption and thickness swelling of OSB made from mountain pine beetle wood. We found linseed oil mixed with wax or expandable plastic microspheres provides effective short-term resistance to water absorption and thickness swell, but longer-term protection is compromised by the gradual deterioration of hardened linseed oil by water. Industrial coatings-application methods, including spraying and high-speed roller coating, were tested to apply micro-structured water repellents, oils and ultraviolet-cured coatings to OSB surfaces.

Keywords: mountain pine beetle, oriented strand board, dimensional stability, roller coating, emulsion wax, water repellents, linseed oil, microspheres

Résumé

Le panneau de lames orientées (OSB) représente une grande partie du marché du revêtement et de sous-couche de faux plancher; toutefois, à cause de sa faible stabilité dimensionnelle lorsqu'il est exposé à l'humidité, il n'a pas complètement remplacé le panneau de contreplaqué. La fabrication de panneaux OSB constitue l'un des principaux moyens de récupérer la valeur du bois d'arbres tués par le dendroctone du pin ponderosa (DPP). De grandes quantités de bois d'arbres tués par le DPP ont déjà été transformées en panneaux OSB dans l'Ouest canadien. Les principales difficultés liées à l'utilisation d'arbres tués par le DPP pour en faire des panneaux OSB consistent en la sécheresse des billes, une plus grande fragilisation et la propension du bois à se briser en fragments plus petits au cours de la production de lames OSB, réduisant ainsi la résistance à l'humidité et la stabilité dimensionnelle du composite. La réhydratation des billes et la modification des schémas de pressage pour les panneaux OSB ont permis au bois d'arbres tués par le DPP d'être utilisé dans la production de contreplaqués; néanmoins, il reste tout de même à élaborer des solutions pratiques au problème lié au niveau élevé d'absorption d'eau et au gonflement en épaisseur des contreplaqués.

Dans le cadre du projet, on a examiné toute une gamme de différentes technologies de revêtements et de produits hydrofuges visant à réduire l'absorption de l'humidité et le gonflement en épaisseur des panneaux OSB faits de bois d'arbres touchés par le DPP. Nous nous sommes rendu compte que l'huile de lin mélangée à des microsphères de cire ou de plastique expansible offrait une résistance très efficace à l'absorption d'eau et au gonflement en épaisseur, à court terme, mais que la protection à plus long terme était compromise par la détérioration graduelle de l'huile de lin par l'eau. Les méthodes industrielles d'application de revêtements, y compris l'atomisation et l'application au rouleau à grande vitesse, ont été mises à l'essai pour l'application de matériaux hydrofuges microstructurés, des huiles et des revêtements séchés par ultraviolet à la surface des panneaux OSB.

Mots clés : dendroctone du pin ponderosa, panneaux OSB, stabilité dimensionnelle, application au rouleau, cire de type émulsion, produits hydrofuges, huile de lin, microsphères.

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1 Introduction

The mountain pine beetle (MPB; *Dendronctonus ponderosae* Hopkins and *D. monticolae* Hopkins) and its associated ophiostomatoid blue-stain fungi have prematurely killed millions of hectares of lodgepole pine trees in British Columbia's and Alberta's forests. In British Columbia alone, more than 14.5 million hectares have been affected (as of 2008), representing approximately 620 million m³ of standing beetle-killed wood (BCMoFR 2008). The strategy adopted by the Province to deal with the problem has been to harvest affected trees as quickly as possible in order to avoid further deterioration of the wood, to reduce fire hazards and to try to reduce the rate of spread of the beetle to healthy stands. This means that many sawmills and board-manufacturing facilities are having to process large quantities of blue stain-affected wood (Byrne 2003).

The sapwood of beetle-affected trees is colonized by ophiostomoid blue-stain fungi; furthermore, beetle-affected trees dry out rapidly on the stump. The recovery of maximum economic value from this damaged wood resource is a challenge as wood quality deteriorates over time, making the wood less suitable for structural timber. Fortunately for wood recovery, blue stain is not a mould and does not adversely affect the strength of solid wood or composites. However, it poses a serious marketing problem, because the general public is not familiar with differences between mould and wood-staining fungi (Byrne, 2005 workshop presentation).

The manufacture of oriented strand board (OSB) has been identified as one of the major ways in which value can be recovered from mountain pine beetle-killed wood; there are currently three OSB mills in the affected region of British Columbia and Alberta using beetle-killed logs for the manufacture of panels. The main problems associated with processing beetle-killed wood for OSB manufacture are its dryness and its increased brittleness and propensity to fragment into smaller pieces during stranding (Byrne, 2005 workshop presentation; Feng and Knudson 2007; Feng and He 2007). The increased amount of fines and the greater permeability of beetle-killed wood (Woo et al. 2005) increase resin consumption during blending, and alter mat-void space. This creates boards that are more susceptible to thickness swelling (Dai 2004).

At the moment, the majority of OSB products, including those made from beetle-killed wood, are confined to interior flooring, and wall and roof sheathing—applications where the product is normally protected from moisture. Oriented strand board products are most vulnerable to wetting in buildings during the early stages of construction before the structure is closed up. Completion of dwellings can be delayed by several weeks or months from the time OSB products are installed as flooring or sheathing to when the dwelling is sealed up. The high dimensional instability of OSB compared to plywood or solid wood reduces its suitability for exposure. Commodity-grade OSB wall, roof and floor sheathing absorbs water through the product's unsealed surface and edge voids; when wet, it swells in thickness (Brochmann et al. 2004; Van Houtts et al. 2004, 2006). This, in turn, results in strength loss and localized board failure at joints, facilitates further ingress of moisture into unaffected portions of boards, reduces creep resistance of boards under their own and external loads (Vun and Beall 2004), and provides the vector for fungal attack (Ye et al. 2006). Exposure to prolonged or cyclic wetting reduces commodity-OSB strength and physical properties far more than it reduces those of OSB's closest competitor, plywood.

Modifications to stranding, screening, mat forming and pressing for processing OSB from beetle-killed wood have helped mills adapt; however, little attention has been paid to the application of surface treatments and coatings to further reduce OSB susceptibility to moisture and thickness swell.

The goals of this project were threefold: to develop coatings technologies that could seal the capillary networks in the surface of OSB that allow water to penetrate the composite and cause excessive thickness swell, and; to develop effective water-repellent and surface-finishing systems

to reduce or prevent the penetration of water into the subsurface of boards while, at the same time, improving the quality and smoothness of OSB for surface finishes.

Research included five experiments to investigate different types and applications of water repellents and coatings. The first two experiments tested different commercial and custom-made wax emulsions as spray-on water repellents to dimensionally stabilize OSB. Two experiments examined alternative coating types (cross-linking linseed oil with and without wax, and a variety of commercially available coatings such as acrylics and urethanes) and surface texturing/void filling with micronized particulates to modify water-droplet behaviour and penetration into boards. The final experiment investigated, on a pilot scale, roller coating for applying coatings to flat panels.

This report reviews all five experiments. The techniques and apparatus used in one or more of the experiments (such as the contact angle measurement device, spraying- and roller-coating equipment, and thickness swell testing and measurement facilities) are described first; the experimental designs and other information specific to each experiment follow.

2 Materials and Methods

2.1 General Treatments

2.1.1 Water repellent/ultraviolet oil application via a high volume low pressure spray gun

Water-borne wax emulsions and ultraviolet- (UV-)cured coatings were applied using a high-volume, low-pressure (HVLP) spray gun and pressure pot (Figure 1b). Whereas the UV oils applied evenly to cold boards, the wax emulsion water repellents tended to bead: the spray specimens therefore had to be preheated in order for the treatment to be applied evenly. Edge- and bottom-sealed specimens were preheated in an oven set at 105° C overnight between small 25-mm thick steel plates (Figure 1a). Specimens were removed from the oven and sprayed according to the experimental design. The top surface of the American Society for Testing and Materials (ASTM) thickness swell specimen was sprayed first, then weighed; the liquid was allowed to soak in for 1 to 2 min. Then the bottom surface was sprayed; then the top surface of the swellometer sample. The specimens were placed horizontally on a platform and sprayed from above at a distance of approximately 25 cm in one pass of approximately 1 s duration from one side of the specimen to the other. The spray gun nozzle was 0.5 mm and pot pressure was set at 103.4 kPa (15 psi), and air pressure supplied to the gun was 206.8 kPa (30 psi). After each spray pass, the specimen was weighed in order to determine how much wax had been applied. Specimens were allowed to equilibrate for three days before weights and thicknesses were measured.

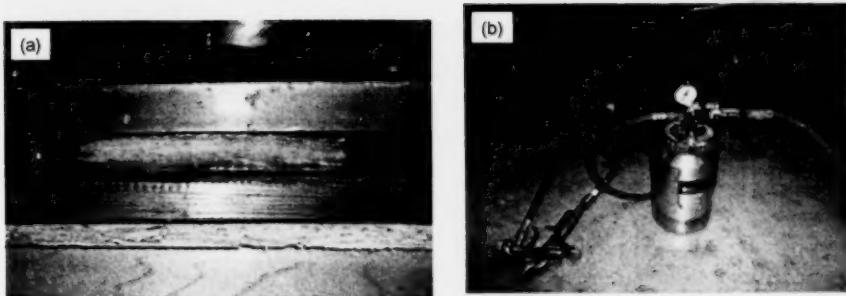


Figure 1. (a) Specimen between heated plates, and (b) HVLP spray gun and pressure pot used to apply wax emulsions to board surface.

2.1.2 Application of water repellents containing glass microspheres

Glass microspheres of various sizes were applied to the surface of OSB in a water-repelling carrier solution. Use of a different type of spray applicator than the HVLP system was required for two reasons: the larger of the calibrating microspheres were too large to pass through the nozzle of the HVLP spray gun without blocking it, and the limited quantity of calibrating glass microspheres required a smaller batch of treatment solution. For this purpose, a small-scale airbrush with an adjustable nozzle opening was used. Five millilitres of water-repellent solution was sprayed onto each side of an OSB sample measuring 3.5 cm x 13.5 cm that had been edge sealed with marine epoxy and preheated to 120° C. The spray was applied using a small Badger brand artist's sprayer (Figure 2a) with canned propellant. The glass microspheres floated to the top of the vials when the solution was not agitated (Figure 2b). In order to administer the solution as an even dispersion of microspheres (Figure 2c), it was first swirled, then immediately sprayed across the first quarter of the specimen. This process was repeated until all four zones of the piece had been sprayed. The specimen was rotated 90°, and the stepwise spraying process repeated. After this, the other side of the specimen board was sprayed in the same manner.

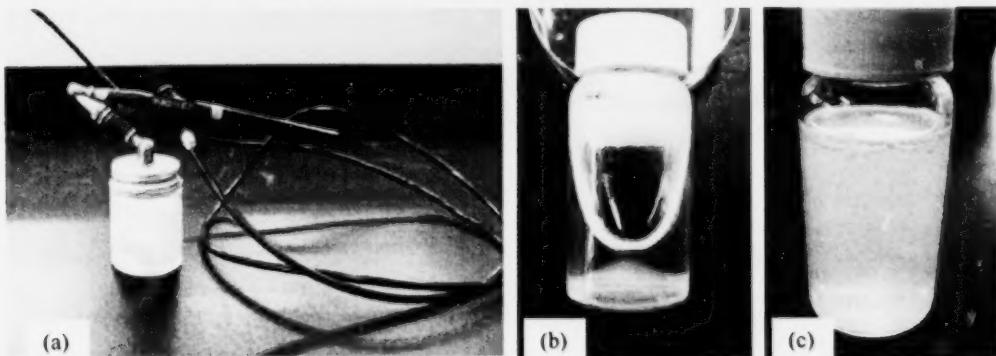


Figure 2. (a) Badger artist's airbrush with adjustable nozzle opening, (b) undispersed microspheres, and (c) dispersed microspheres (by agitation). In (b) and (c), microspheres are shown in water for clarity.

2.1.2.1 Roller coater and ultraviolet-curing unit

The roller coater used to apply coatings to OSB was a Bürkle laboratory-scale roller coater (Figure 3). This was equipped with one 7-cm diameter steel doctor roller and one larger (10.2-cm) smooth rubber applicator roller. The belt-feed speed for the boards through the roller coater was 15 m/min. After preliminary trials, it was found that a gap of 0.1 mm between the doctor roller and the applicator roller was best for applying an even film of finish to boards. A wider gap left

globs of finish on some surface strands, and a narrower gap left no finish in some places. Where UV-cured oil was used, this was cured using a Bürkle UV-cured unit (Figure 4). The feed speed of the boards under the UV lamps was 8 m/min. The weight of every board was recorded prior to roller coating and again immediately afterwards.

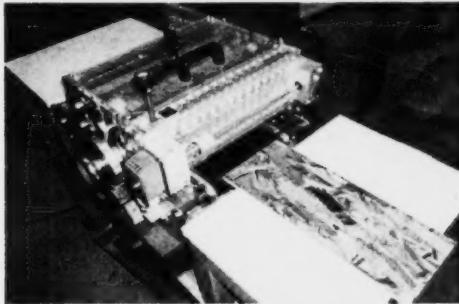


Figure 3. Bürkle laboratory-scale roller-coater machine.

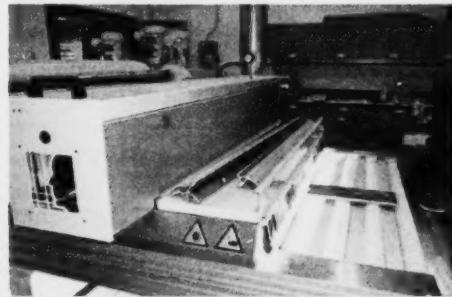


Figure 4. Bürkle UV-cured unit for UV-cured oils.

2.1.3 Contact angle recorder

Surface contact angle for water was measured in all experiments. The ability of water to wet the surface of wood can be quantified using contact angle measurement. Surface wettability of coated board surfaces was evaluated using a droplet contact angle-measuring device (KSV CAM101 from KSV instruments, Glen Burnie, MD; Figure 5a). A droplet of distilled water measuring 1 mm in diameter was placed on the specimen surface via a syringe dispenser and recorded from the side (Figure 5b) every 30 s for 60 min using a mounted camera and image-capture program. In cases where the surface was very wettable, droplets were recorded every second for 5 min, and every 30 s over 100 min for non-wettable surfaces. Variables used to compare the wettability of surfaces were average initial contact angle (C_i) and the average time (min) taken for 10 droplet samples to spread, evaporate or penetrate the surface, reducing the droplet contact angles to 50°.

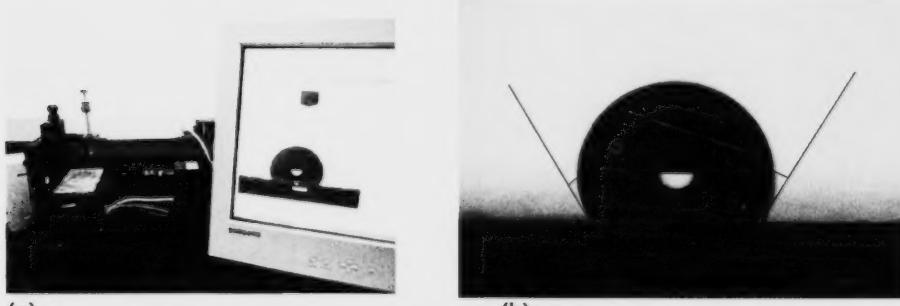


Figure 5. (a) KSV CAM 101 contact angle recorder, and (b) example of a water droplet on a hydrophobic surface with a contact angle of above 90°. Static contact angle (C_i) is the average of θ_1 and θ_2 .

2.1.4 Measurement of thickness swell and water absorption

2.1.4.1 American Society for Testing and Materials specimens

The American Society for Testing and Materials (ASTM) D1037 (2000) standard was used to determine thickness swell response of the treated OSB boards. For each replicate block and treatment, a 15.2-cm x 15.2-cm square of OSB was cut. All four edges of this were then sealed using G-2 marine epoxy resin (Industrial Formulators, Port Coquitlam, BC), which sets over 24 h to form a tough, impervious edge seal. Prior to immersing the specimens in water for thickness swell testing, weight and thickness at four marked points around the sides of each specimen were measured using a 30.5-cm digital caliper. The jaws of the caliper extended a distance of 5.1 cm into the centre of the specimen from the edge.

The thickness swell specimens were placed into a 100-gallon-capacity swell tank (Figure 6a) fitted with bars designed to hold the specimens in a horizontal position approximately 30 mm below the surface of the water at 20° C. After 2 h, 6 h, 24 h, and 48 h of soaking, the specimens were removed, drained of excess water for 5 min, weighed, and their thicknesses were remeasured (as above).

Thickness swell at the different soaking times was calculated as a proportion of the original dimensions of the specimen prior to immersion.

2.1.4.2 Swellometer specimens

Adjacent to each ASTM thickness swell specimen for a particular treatment and replicate, a 7.6-cm x 12.7-cm swellometer specimen was cut from OSB. These were coated with the marine epoxy on the four edges and on the bottom, leaving the coating formulation on the top surface only. Where an experiment had eight treatments per replicate block, all eight swellometer specimens from one replicate block were randomly assigned to a linear transducer channel of the swellometer (Figure 6b). The linear transducer head was zeroed onto the dry surface of each specimen, the tank was filled with water at 20° C, and the swellometer set to read surface height in millimetres and percent of original. The transducers were recorded every five min for the first 24 h, and thereafter every 30 min for the next five days. As the bottom surface was sealed, thickness swell was calculated as change in surface height proportional to half the specimen thickness.

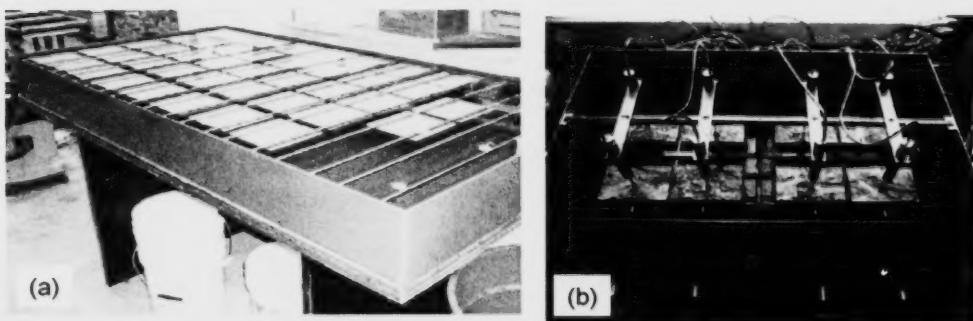


Figure 6. (a) Thickness swell tank, and (b) swellometer. Water has been removed to allow detail to be seen.

2.2 Experiments 1 and 2: Water Repellent Types and Concentration

2.2.1 Background and rationale

One potential approach to solving the poor dimensional stability of wet OSB is to improve its moisture resistance with application of water repellents. The addition of water repellents containing micronized wax-emulsion particles is an effective way of improving dimensional stability of solid wood (Borgin and Corbett 1969, 1970, 1973). Water-repellent formulations have been used for more than 40 years to improve dimensional stability and resistance to checking of preservative-treated solid wood (Belford and Nicholson 1969; Warberton et al. 1991; Evans et al. 2009). This is because, unlike surface film-forming paints and varnishes, micro-particles of wax emulsions can penetrate deep into the capillary structure of wood, and the strongly hydrophobic nature of the wax prevents the uptake of water through the capillaries (Borgin and Corbett 1970).

Micro-emulsions are defined as stable dispersions of one liquid in another in the form of spherical droplets approximately 0.14 μm or 14000A in size. These are less than a quarter of the wavelength of white light (0.25 μm): wax emulsions can be considered to be micro-emulsions (Prince 1974). In fact, carnauba wax (a hard vegetable wax from palm leaves) was one of the earliest types of wax to be used in commercial micro-emulsions, and was developed and first used as a water-based wood-floor wax solution in 1928 by George Roawald, Miracul Wax Co. Since then, use of emulsion waxes has expanded in the wood and paper industries; for example, becoming an integral part of modern wood-preservative formulations (Evans et al. 2009), as well as of resin formulations used in composite board manufacture (Maloney 1977; Winistorfer et al. 1996) and paper manufacture.

Wax emulsions contain micro-meter-sized and, in some cases, nano-meter-sized particles of wax held in a water suspension by a surfactant. The particles are small enough to penetrate into the wood capillaries where they act as water repellents to slow down wood's moisture-absorption rate and resultant swelling (Borgin and Corbett 1969, 1970, 1973). Because of this, they are classified as water repellent treatments rather than as dimensional stabilisers that chemically modify the wood-cell wall and prevent it from adsorbing water and swelling. This means that, once administered to a wood surface or into capillaries via pressure/vacuum treatment (for example), wax emulsions work by temporarily repelling water from the wood and by retarding its uptake and the consequent swelling of the cell wall of solid wood or of strands in a composite board. Because water is able to displace the wax from the hydrogen-bonding sites on the wood polymers, after being exposed to water for hours or days, depending on wax loading and formulation, the wax-emulsion-treated wood eventually will swell to equal the thickness swell of an untreated control (Borgin 1961; Borgin and Corbett 1970).

The main objective when using water repellents is to apply a cost-effective treatment to the wood surface (or subsurface, in the case of pressure-treated wood) that will slow the rate of water absorption into the wood during temporary wetting events. Most rain showers are transitory, and if left exposed to the elements wood will experience intermittent wetting and drying cycles.

The application of wax emulsions to the surface of OSB deposits a small amount of wax over the surface and into crevices and is able to delay the adsorption of water into the wood during temporary wetting events. Following such an event, the wood dries out more quickly, because it would not have absorbed as much water as it would if it had been untreated.

The waxes used by the wood industry are colloidal solutions of micronized paraffinic wax particles (around 1 μm) surrounded by an ionic-charged surfactant that keeps them separated from each other (Maloney 1977). Maximum wax loadings can vary, depending on wax type and surfactant system, but normally lie somewhere between about 25% and 40%, and are diluted by the end user to usually less than 2% for use in composite manufacture or preservative treatment. Due to the large quantities and the consistency in properties of waxes produced from crude-oil

refining, the most common waxes used in industrial wax emulsions are the paraffinic type,. Waxes derived from natural sources such as beeswax or plant waxes are produced at generally too small scale to be economic for use in industrial formulators; natural waxes also vary in quality and properties.

Wax is a relatively low-cost component of OSB production and, therefore, it has received little attention from researchers. Because higher levels of wax addition can adversely affect bonding in composite boards, the dosage is restricted to less than 1% to 2%, which is insufficient for creating a high degree of moisture resistance (Maloney 1977). Some work has been done on formulating wax-based resin additives and edge sealants for OSB panels, but no published information exists on the use of wax-based water repellents to OSB surfaces. One current patent application for spraying latex-free wax emulsions onto OSB mats or pressed boards claims to improve the OSB moisture resistance; however, no information as to wax type, application rates, or board thickness swell or water absorption are given (Racota 2007). In fact, little published information on the swelling behaviour of OSB, even without post-manufacture surface treatments, exists.

The water repellent phase of this research project included these two experiments:

1. the testing of two commercial wax-emulsion products (one used in the composite board industry and one used in the wood-preservation industry) in different concentrations for reducing OSB water absorption and thickness swell, and;
2. the custom making and testing of emulsions of a range of waxes other than the standard paraffinic waxes used in the commercial formulations.

2.2.2 Oriented strand boards

The OSB used for the water-repellent experiments and throughout this project was commodity-grade 1.1-cm OSB, each board measuring 2.2 m x 4.4 m x 11.11 mm. The OSB sample boards were supplied by Ainsworth Engineered Wood (100 Mile House, British Columbia). The boards were manufactured for general use as wall sheathing, roof decking and subfloor decking, and have a span rating of 40.6 cm or 406 mm. They were manufactured to contain approximately 65% mountain pine beetle-killed lodgepole pine and 35% aspen. Average board density was 632.73 kg/m³ (39.5 lb/ft³). The boards were manufactured with 1% to 2% wax content, with greater wax dosages in the surface layers.

2.2.3 Waxes

For Experiment 1, two emulsion waxes were used as surface treatments: one (Wax A) is a formulation used in the OSB manufacturing industry (Borden Cascowax EW-50S; 50% solids content); the other (Wax B) is a water-repellent additive for wood preservatives (UW5F; 40% solids content) supplied by Viance LCC (Charlotte, North Carolina). The concentrated stock solutions were diluted using tap water to make up six batches of 2-L spray stock solutions at three different concentrations: 0.5%, 2.5%, and 5%. Water containing no wax was used as a control (Wax A or B at 0%).

In Experiment 2, four custom-made emulsions and two commercial emulsions (the same as those used in Experiment 1) were used, all at 1% concentration. The custom-made emulsions were soy wax (based on hydrogenated soya bean oil), beeswax, and carnauba wax.

2.2.4 Experimental designs and statistical analysis

For Experiment 1, six replicate boards were cut lengthwise into four 30.5-cm-wide strips (Figure 7). The outer strips were discarded, and the centre two strips were randomly assigned to one of the two wax types. The wax-assigned strips were then cut into four sections, each measuring 30.5 x 61 cm. Each was randomly assigned a wax concentration (0%, 0.5%, 2.5% or 5%). Each of the eight sections per board was labelled with a numeric code for board/wax type/concentration.

The experiment was designed and analyzed as a split-plot design using Genstat 10. From the centre of each board/wax/concentration piece, a 7.62-cm x 12.7-cm swellometer specimen and a 15.24-cm x 15.24-cm ASTM thickness swell/length expansion specimen were cut.

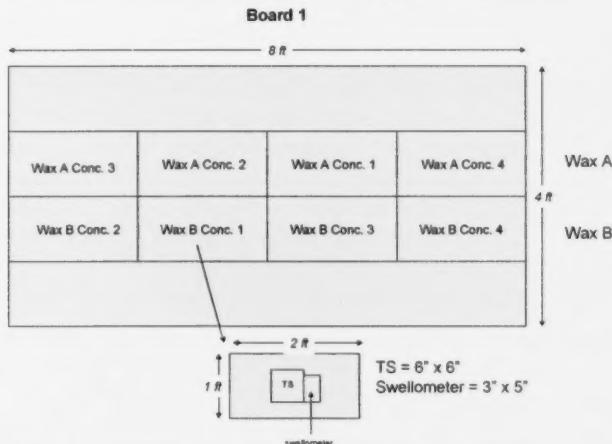


Figure 7. Sampling layout of OSB panels for emulsion wax/concentration treatments.

For Experiment 2, three replicate boards were similarly divided into eight sample pieces, each measuring 1 ft x 2 ft (Figure 8). Rather than having concentrations nested within wax types, a set of eight treatments (no treatment, water spray only, 1% soy wax, 1% beeswax, 1% carnauba wax, 1% Cascowax, and 1% UW5F) was randomly assigned to the eight samples, with a different randomisation for each parent board.

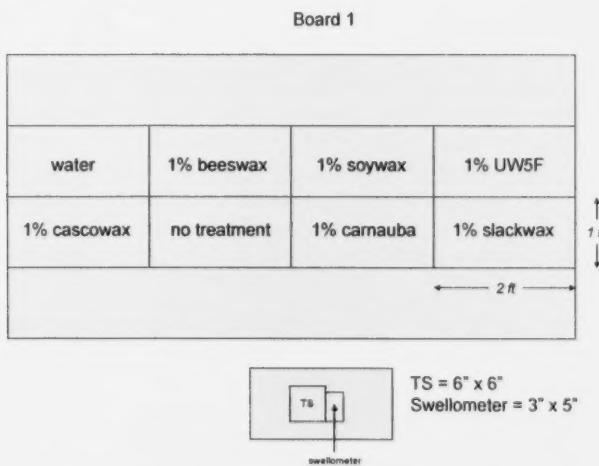


Figure 8. Sampling layout of OSB panels for custom-made emulsion wax treatments.

Thickness swelling and water absorption are normally expressed as a percentage of the original specimen thickness or weight. For the purposes of statistical analysis, the data for thickness swell and water absorption were analyzed as the ratio of soaked-specimen thickness or weight change during each of four soaking periods (2 h, 6 h, 24 h and 48 h) to unsoaked-specimen thickness or

weight. Each measured variable, i.e., thickness swell and water absorption for each soaking period, and length expansion at 24 h were analyzed using separate analysis of variance (ANOVA) models, using a significance level of $p \leq 0.05$. An ANOVA for thickness swell and water absorption that incorporated soaking time as a factor was also run. Diagnostic checks for data distribution and equal variance were carried out prior to data analysis.

2.3 Experiment 3: Oil-Based Coatings Containing Wax

2.3.1 Background and rationale

The next phase of the project examined inexpensive drying oils that contain water-repellent waxes for use as a potential water-retardant coating for OSB to reduce moisture ingress and thickness swell. Drying oils have at least three potential practical benefits compared to water-based wax emulsions: 1) their use is far more flexible, in that they can be applied to either hot or cold board surfaces; 2) the OSB strands do not absorb the water in the formulations, and swelling does not occur as part of the treatment, and 3) the drying oils have the capacity to cross-link and form a harder, thicker, and more water-resistant surface and possibly subsurface network. These properties were expected to give greater water resistance than the emulsion-wax solutions on their own did.

Naturally derived vegetable oils from pressed nuts and seeds have been used for millennia as treatments to reduce susceptibility of exposed wood to water and prolong its life; for example, early ship-builders such as the Vikings and ancient Greeks were aware of the oils' capacity to slowly harden with exposure to air and sunlight into a tough, moisture-resistant barrier, and commonly used natural oils and waxes as repeatable timber treatments easily applied by steeping, rubbing or brushing on. The ancient Egyptians were other early users of drying oils and produced linseed oil from flaxseed of flax grown for fibre; the ancient Greeks from the 1st to 6th centuries produced and used walnut, poppy and linseed oils for wood protection; in the 1st Century AD, the Chinese and Japanese made artistic paints and lacquers from nut and seed oils (Mills and White 1999). These oils were employed for their ability to dry and harden with time to form a tough yet flexible coating, and later in Europe were used increasingly as a base for paints. European references to the application of these seed- and nut-based oils as bases for artistic paints appear in the early 15th Century, with Flemish masters Hubert and Jan van Eyck among the first to use drying oils in oil painting. These early artists modified the virgin oils by a combination of boiling (boiled linseed oil being an example of such modified oil) and mixing with the pigments used at the time (these often were oxides of heavy metals such as lead, mercury, cobalt, tin, iron, etc.) to make them dry faster than unadulterated virgin oils, which required days and weeks to dry. The metals accelerate the oils' polymerization process. Whereas, today, a much wider range of paints, including latex and water-based paints, are available, heavy-duty exterior paints that use drying oils as the base are still common.

The basic chemistry and curing of drying oils is reviewed in Wheeler (1950), Heaton (1984) and Mills and White (1999). Drying oils contain glycerol esters of fatty acids, which are long hydrocarbon chains with a terminal carboxyl group. They dry, not through the evaporation of the solvent water, but through the slow process of auto-oxidation, an exothermic reaction of oxygen from the surrounding air that attacks the hydrocarbon chain to generate highly reactive free radicals, often at the site of an allylic hydrogen (a hydrogen atom on a carbon atom adjacent to a double bond). This allows the cross-linking and polymerization of fatty acid chains. The ability to form a cross-linked polymer skin is made possible by high levels of polyunsaturated fatty acids, primarily alpha-linolenic acid, present in drying oils such as linseed oil. Polymerization is irreversible and forms a durable material through covalent bonding.

The polymerization process of unadulterated vegetable oils is too slow for most industrial processes and is hampered by the presence of natural antioxidants, which prevent the oil from polymerizing while still in the plant tissue. A second phenomenon that slows the curing process

of a film of drying oil, especially if it is thick, is the curing of the top surface. This is exposed to air, which forms a pre-cured skin and blocks access to oxygen for curing the film's lower layers (Richey 2000). To overcome this, commercial boiled linseed oil products contain small amounts of heavy-metal salts. These act as drying agents and reduce drying times from weeks to around 24 h (Pennock 2005). Cobalt and zirconium are commonly used salts, but other agents that are used can contain more toxic metals, such as lead, chromium, beryllium, cadmium and nickel. For example, commercial urethane oils for coatings are prepared by reacting partially hydrolyzed drying oil (linseed oil) with glycerin and a cross-linking catalyst such as cobalt naphthanate (Petrovic 2004).

Raw or boiled linseed oil is a very common water repellent base for wood paints and stains and is classified as having medium hydrophobic properties (Borgin 1961). Pure linseed oil has been shown to successfully enhance the water repellency of wooden elements used to manufacture cement-bonded building materials (Basta et al. 1996). To create an optimum water-resistant furnish, they pressure-impregnated the furnish for 10 min with 50% linseed oil and hardened it for 3 h at 120° C.

One common measure of the siccative (drying/hardening) property of oils is their iodine number—an indicator of the number of double bonds in the oils' fatty acids. Oils such as linseed oil that have an iodine number greater than 130 are considered to have a high cross-linking capacity.

Two of the primary disadvantages of oil-only wood finishes that contain even pre-boiled oils are the relatively slow drying and hardening times (hours and days) and only marginal longer-term protection from water (Borgin 1961; Mills and White 1999; Richey 2000). One common component of oil-based wood finishes is a drying solvent such as mineral spirits or turpentine that makes the finish easier to apply in a thinner and faster-drying coat, hastening the touch-dry point of the finish. The water-repellency capacity of an oil-based finish is enhanced with the addition of a wax, such as beeswax or paraffin wax, which is classified as a water repellent with strongly hydrophobic properties (Borgin 1961). The presence of wax can also hasten the setting time for the finish (Richey 2000).

The aim of this section of the research project was to test the capacity of one coat of various linseed oil-wax mixtures to repel water from OSB and restrict water uptake and thickness swell over time, compared with one coat of other commercial reference coatings manufactured mostly for application to wooden articles.

Commercial boiled linseed oil containing drying agent was chosen over tung oil for both cost and its faster curing rate.

2.3.2 Design

For Experiment 3, three replicate 4-ft x 8-ft panels of the same batch of OSB described in Section 2.3.2 were used. These were divided up into a total of 16 square samples measuring 30.5 x 30.5cm, each of which was randomly assigned a treatment number between 1 and 16 (Figure 9). These treatments included the oil-wax formulations and a variety of reference coatings. From each of the samples, a 15.2-cm x 15.2-cm square ASTM thickness swell sample and a 7.6-cm x 12.7-cm swellometer specimen were cut and the edges and bottom were sealed with marine epoxy resin prior to applying the coatings.

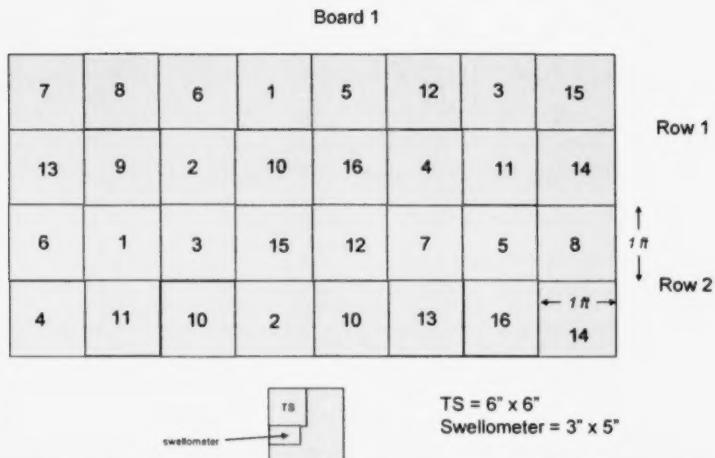


Figure 9. Schematic diagram of the randomized sampling of parent boards of OSBs.

2.3.3 Coatings and application

The following types of coatings treatments were prepared and applied to OSB samples:

2.3.3.1 Experimental drying oil-based coatings

- 1) Double-boiled linseed oil applied to a hot or cold board surface and heat set.
- 2) Grated wax (0.1 g/mL) dissolved in linseed oil. Waxes used were natural animal and vegetable waxes: soy wax, beeswax, carnauba wax and paraffin wax (synthetic Fischer-Tropsh wax). These were applied hot to keep the wax dissolved.

A distinguishing feature of this type of coating was it had to be applied warm or hot depending on wax type: 20 mL of linseed oil were warmed up in a beaker on a hot plate, and as the temperature reached about 50° C, 2 g of grated wax, or small flakes in the case of carnauba wax, were stirred into the oil until the wax dissolved. Oil temperature needed to be above about 80° C for the carnauba wax and the paraffin wax to dissolve completely.

2.3.3.2 Reference coatings

Commercially available water-resistant clear-coating sprays were assigned treatment numbers and applied either by brush or spray (if it came in a pressurized can) to OSB samples. Coating performance after one application (coat) in relation to one coat of the custom oil-wax coatings were compared. Because the commercial products were applied at less than the manufacturers' recommendation of more than two coats, one of them (Diamond Varathane, a clear coating made specifically for the protection of outdoor wood) was applied according to the manufacturer's recommendations: four brush-on coats, each with a day between to dry each coat.

The reference coatings are as follows:

Shellac (spray can);

Urethane (brush)

Diamond Varathane (brush): four coats with one day drying between coats;

Aqua Farblos from Adler (brush);

Stainguard water repellent for natural fabrics (spray can);

White water-borne lam-print basecoat (brush);

Mineral oil (brush);

The oil-wax coatings and the reference coatings together comprised a total of 15 different treatments (including one no-treatment control), plus one extra for Experiment 3. Each treatment was randomly assigned to each of the 16 sampling locations on each parent board. Treatment sample numbers are provided in Table 1.

Table 1. Treatments applied to OSB samples.

Treatment	Treatment
1. Control (no treatment)	9. Shellac
2. Commercial wax emulsion (1%)	10. Urethane
3. Linseed oil (cold surface)	11. Acrylic
4. Linseed oil (hot surface)	12. Stainguard™ cloth protector
5. Linseed oil + paraffin wax	13. Mineral oil
6. Linseed oil + carnauba wax	14. Diamond Varathane
7. Linseed oil + beeswax	15. Melted wax powder
8. Linseed oil + soy wax	16. Lam-print basecoat

Treated specimens were allowed to dry and condition for 1 to 2 weeks before surface-contact angle and thickness swelling/water absorption were measured using the equipment and methods described in Section 2.3.1. For the purposes of statistical analysis, linseed oil and linseed oil-wax treatments were pooled together into the two umbrella groupings, *oil* and *oil-wax*, where there were no significant differences between individual treatments. These were compared with the *no treatment-control* and *emulsion wax* groups.

2.4 Experiment 4: Board Treatments Containing Micro-Texturing and Pore-Blocking Agents

2.4.1 Background and rationale

In an attempt at improving performance of water repellents or oil-based coatings in protecting OSBs from moisture, the next phase of the project focused on the physical modification of the board surface and the use of particulates to block surface voids. Surfaces that have engineered roughening can be either more or less hydrophobic than a smooth surface, depending on the surface chemistry and the size and geometry of the roughening (Parkin and Palgrave 2005). Engineered surfaces designed to influence surface hydrophobicity are common in nature. For example, nodulation of the xylem cell wall makes the tracheid surface of plants more wettable, causing lumen water that is under tension to spread more easily and reduce the incidence of bubbles (or embolisms) in plant conductive tissues (Kohonen 2006). In many herbaceous aquatic plants, a combination of micro- and nano-texturing of leaf surfaces in combination with hydrophobic surface chemistry (such as a waxy or *glabrous* surface) makes the surface very strongly hydrophobic, causing water to bead and roll off, taking dirt with it. This surface texturing is found in more than 200 known species of plants, and is known as the *lotus effect* (Barthlott and Neinhuis 1997).

Industry has imitated this texturing to create non-stick surfaces such as Teflon-coated cookware, and self-cleaning nano-films for glass windows.

2.4.1.1 Glass microspheres as surface-texturing agents

The aim of the first part of the surface micro-texturing study was to test the effects on surface hydrophobicity of OSB of adding industrial-glass microspheres (fibreglast) in different carrier solutions.

The first step in this process was to deposit industrial-glass microspheres (which are approximately 40 µm in size) onto the surface. Glass microspheres were chosen because of their regular spherical shape, controlled particulate size, and ability to be dispersed in water with mild agitation.

2.4.1.2 Microspheres as void-blocking agents

The second objective of the particulate-effects study was to use small-sized (2 to 40 μm), fixed-size and expanding microspheres in a solution that could penetrate OSB and deposit the particulates in voids--a process that may succeed in blocking moisture ingress. Glass and phenolic microspheres have been used as lightening and filler agents, respectively, for cements and concretes (Oreshkin and Ippolitov 2003) and for epoxy-based wood-gap fillers (Barclay and Mathias 1989). They may also form packing materials that could fill or partially fill surface voids in OSB and create a bulk pore-blocking effect against moisture. The third type of microsphere investigated, expanding microspheres, were expandable plastic types that are produced as foaming and filling agents for a variety of fibreglass-reinforced thermosetting composites and extruded forms. These are produced by AkzoNobel under the trade name Expance. They are among the lightest fillers available, with standard specific gravities for Expance being as low as 0.025, and provide large volume displacement at a very low weight. The impart to materials an enhanced ability to withstand high fluctuations in temperature that cause cyclic expansion and contraction of the matrix and eventual fissuring (Wood 2008): because they are able to expand and contract in size with the surrounding polymer matrix, the microspheres help dissipate the internal stresses caused by matrix expansion and contraction. Expance has been tested as a lightweight core material for hot-pressed-wood-based composite panels and extruded wood-plastic composites (Luedtke 2008; Wood 2008).

An Expance-brand microspheres consists of a very thin thermoplastic shell (made of a copolymer, such as vinylidene chloride, acrylo-nitrile, or methyl methacrylate) that encapsulates a hydrocarbon blowing agent, typically isobutene or isopentane (Wood 2008). When heated, the polymeric shell softens, and the liquid hydrocarbon gasifies and expands. When heat is removed, the shell stiffens, and the microsphere remains in its expanded form. Expansion temperatures range from 80° C to 190° C, depending on the grade. The particle size for expanded microspheres ranges from 10 μm to 150 μm , and the eventual expanded size of one grade of expanding microspheres in a thermoset composite varies greatly. For this study, 20- μm , 40- μm and 80- μm sizes were obtained.

Since plastic microspheres are used as fillers and bulking agents for resins and thermoset polymers, another objective of this study was to use them as a filler to produce a thicker and more durable kind of oil-based coating that may enable the coating to remain on the surface while curing instead of seeping in, and also to withstand stress caused by swelling of the substrate.

2.4.2 Treatments

The OSB and the test-sample dimensions replicated those described in Section 2.3.2. In the first study of Experiment 4, five different kinds of glass microspheres were used: four grades of sieve-calibrating microspheres (from Whitehouse Scientific, U.K.), and one grade of standard industrial microspheres (from Fibreglast Corp., OH, USA) that is commonly used as a paint additive. Three test loadings were mixed, for a total of 15 treatment combinations. Pieces representing one replicate block were sprayed with the 15 different microsphere/loading combinations, with one piece left as a control treatment *control*. The sample-cutting pattern of 30.5-cm squares, with a randomly assigned treatment, from the parent boards is similar to that shown in Figure 6.

The aim was to try to use an aqueous medium that contained hydrophobic emulsified wax to carry the spheres evenly over the surface and into surface crevices. Initially, three different kinds of carrier solution were tested: a UW5F wax emulsion solution at 1% solids; a commercial water-based acrylic (Aquacryl Farblos), and; polyurethane (Acqua Ferroclair) wood coatings diluted 75% with water so that their polymer-solids content was reduced to approximately 10%. Twenty millilitre aliquots of these solutions were placed into glass vials; a small quantity of industrial glass microspheres (fibreglast) weighing 0.03 g was added to each and swirled in. This was the equivalent of 0.0015 g/mL of spheres.

Table 2 lists the grades of microspheres and their test loadings.

Table 2. Microsphere grade (size class) and loading.

Microsphere grade	Loading
38-45 μm calibrating	Low (0.01 g/20 mL)
63-75 μm calibrating	Med (0.05 g/20 mL)
90-120 μm calibrating	High (0.2 g/20 mL)
180-212 μm calibrating	
Industrial microspheres (\approx 40-80 μm)	

The industrial microspheres were much lighter in weight than the calibrating glass microspheres. To maintain better consistency in volume, weights of the industrial microspheres were adjusted to the following: low (0.001 g/20 mL), medium (0.01 g/20 mL), and high (0.05 g/20 mL). The weights of microspheres indicated above were added to 20-mL solutions of low-concentration emulsion wax (UW5F, 1%), and mixed.

Spraying a continuous layer of microspheres of all sizes on the surface of OSBs was not possible. Sprayer nozzles were unable to eject larger microspheres, and when the water in the carrier dried off it redistributed particulates. To create a model system of a continuous layer of microspheres on the surface of OSBs, moisture-proof melamine formaldehyde (MF) resin was applied to the surface by brush and a dusting of microspheres was applied. Obtaining a continuous film of melamine resin on the surface was challenging even when the board surface was heated, because of the very high surface tension of the resin. The board surface had to be heated to at least 120° C, and the resin spread repeatedly using the brush. However, even when this was done, the resin could not be spread as a continuous film. Spray application of the resin broke up into discrete droplets even on the heated board surface. The samples were weighed before and after resin addition and microsphere addition to determine the approximate spread rate. The samples were then heated to 120° C for 5 min. to set the melamine resin.

The second study in Experiment 4 tested expanding plastic microspheres and phenolic microspheres as void-filling materials, with industrial glass microspheres serving as a comparison. These were applied using ethanol, phenol formaldehyde (PF) resin (20% solids), and linseed oil as carrier agents. In the cases of the resin and the linseed oil, the setting of these acted as an adhesive for the microspheres. For this experiment, there were a total of 12 treatments:

1. Expance in ethanol
2. Expance in PF resin
3. Expance in linseed oil
4. Phenolic MS in ethanol
5. Phenolic MS in PF resin
6. Phenolic MS in linseed oil
7. Glass MS in ethanol
8. Glass MS in PF resin
9. Glass MS in linseed oil
10. PF resin only
11. Linseed oil only
12. Control (no treatment)

Five replicate blocks were used in this experiment, and the sample-cutting diagram for replicate Board 1 with its assigned treatment numbers is shown in Figure 10. Treatment randomization differed for each parent board.

Board 1

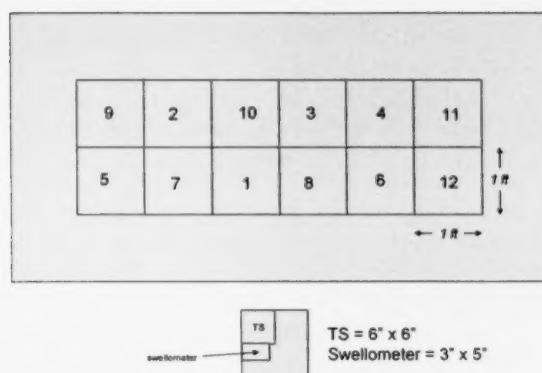


Figure 10. Treatment randomisation for replication block 1 of the surface-micro-texturing/void-filling experiment

2.4.3 Application to boards

The microsphere solutions were first tested by spraying. A 300-mL solution was made up of the carrier solution, and 30 g of microspheres were added and dispersed by shaking the solution in a closed jar. With constant agitation, the microspheres created an even suspension for spraying.

Test OSB samples were sprayed with the solutions to examine evenness of application and to identify problems with this application method. The OSB samples were preheated to allow the water-based media to disperse, but plain water and the diluted PF resin tended to bead up and create a patchy, discontinuous distribution of microspheres on the surface. Other problems included keeping the microspheres evenly dispersed and the nozzle freely spraying. The loading of microspheres in the solution was limited. Plain water as a carrier solution was abandoned due to the need for preheated boards and ineffective distribution.

Because of this, the microspheres were added instead to ethanol, 20% water-soluble PF resin, and double-boiled linseed oil. The only solution suitable for spraying was the one that contained ethanol. The other microsphere solutions were applied by brush. This was especially necessary for dispersing the PF resin solution, which was water based.

Expancel spheres, held together by a hydrolysable caking agent to reduce dust, were very difficult and very slow to disperse evenly in the linseed oil. Using an electric mixer for 15–20 min resulted in considerable dispersion, but the solution still had large and small clumps that blocked the spray lines and nozzle. Hence, it was difficult to make up a large amount of solution for spraying. The presence of even very small clumps of microspheres frequent blocked the nozzle frequently, resulting in uneven application. In this instance, a much smaller amount was used: 10 mL of boiled linseed oil was mixed with 0.3 g of expandable microspheres with an artist's paint brush, taking around 10 min of shear mixing to adequately disperse the microspheres. This solution was applied by brush to the OSB-sample surface at a spread rate of 5 mL per side of the 40.6-cm x 40.6-cm ASTM thickness swell samples, or 0.027 mL/cm².

Boards treated with linseed oil or PF resin were then placed in an oven at 140° C for about 15 min to expand the microspheres. The temperature of 140° C is necessary to cure PF resin, but is at the upper limit of temperature for expanding plastic microspheres. The microspheres are sensitive to prolonged heating beyond about 15 min, whereby we found they would darken and collapse, which rendered them ineffective as water-blocking agents.

2.5 Experiment 5: Roller coating of oriented strand boards

The last phase of this project was designed to examine the roller-coating application of the expanding microsphere treatments onto OSB, and to compare this treatment with more conventional types of finishes that might be applied to panels. The finishes consisted of a commercial water-based water repellent (Thompson's Water Repellent, general purpose), an ultraviolet- (UV-) cured oil (ACI UVO 5062G5-25, Italy), and two experimental finishes that were custom formulations of resin/linseed oil and expanding microspheres. For the two experimental finishes, 20 g of Expance WU 20 grade was mixed with 400 mL of linseed oil or PF resin at 20% solids content using an electric milkshake mixer for 15 min. A few large and small clumps of microspheres remained in the linseed oil mix, but this was not deemed to be a problem for roller coating.

The experiment was divided into 10 treatments across six replicate blocks, which were 4-ft x 8-ft parent boards. The treatments were as follows:

1. UV-cured oil (UVO 5062G5-25), 11 roller coat
2. UV-cured oil (UVO 5062G5-25), 22 roller coats
3. Expanding microspheres mixed in linseed oil, 1 roller coat
4. Expanding microspheres mixed in linseed oil, 2 roller coats
5. Expanding microspheres mixed in PF resin, 1 roller coat
6. Expanding microspheres mixed in PF resin, 2 roller coats
7. Commercial water-based water repellent, Thompsons brand, 1 roller coat
8. Commercial water-based water repellent, Thompsons brand, 2 roller coats
9. Commercial water-based water repellent, Thompsons brand, brush
10. Control (no treatment)

Experiment 5 consisted of a simple randomized block model rather than of a nested design (coats within coating type) due to the fact that no treatment had 0 coats (Figure 11). Treatment randomisation was different for each parent board. Each roller-coated specimen was cut to measure 15.2-cm x 40.6-cm—the size suitable for the small-scale roller coater and which would also fit into the oven for curing. From the middle of each roller-coated specimen, a 7.6-cm x 12.7-cm swellometer specimen was cut and sealed around all edges and the bottom with marine-epoxy resin.

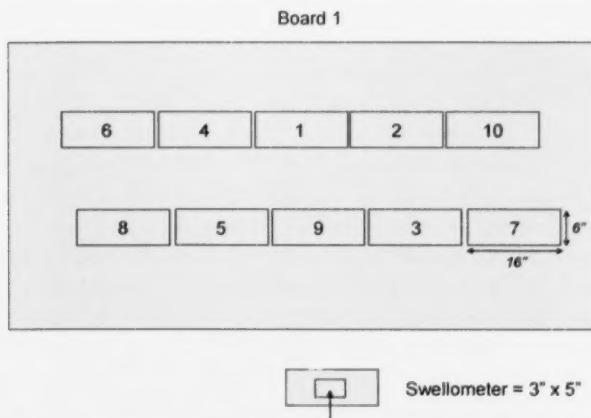


Figure 11. Treatment randomisations for replicate board 1 for the roller-coating experiment.

At the time of writing, the specimens were coated, but the preparation of thickness swell samples and measurement had not been completed.

3 Results

3.1 Experiment 1: Commercial Water Repellents and Concentration

The wax emulsions were the amounts of wax solids applied to specimen surfaces. The average spread rates for different wax concentrations are given in Table 3; these are averaged for each treatment.

Table 3. Wax solids and spread rate for wax emulsion\ spray treatments.

Wax solution	Total solids per surface (g)	Spread rate (g/cm ²)
Cascowax 1%	0.06	0.000250
Cascowax 2.5%	0.16	0.000678
Cascowax 5%	0.41	0.001745
UW5F 1%	0.06	0.000265
UW5F 2.5%	0.16	0.000697
UW5F 5%	0.42	0.001794

3.1.1 Wax application

Early trials found that the board surfaces must be kept hot to allow emulsion-wax solutions to spread over and penetrate into the OSB: This was done by pre-heating boards between steel plates to retain the heat until the surface was sprayed. There was a marked difference in the behaviour of the two wax emulsions even after boards were heated to 120° C. The surface tension of the Cascowax formulated for use in hot pressing remained high even after heating the boards to 120° C. The solution did not spread evenly over the board surface, and its ability to seep into the surface was hampered by beading (Figure 12a). The UW5F water-repellent solution spread out over the hot board surface and seeped in fairly easily within seconds of spraying the board surface (Figure 12b). When emulsion-solution droplets fall onto the hot surface, ideally they should reduce in viscosity, spread more easily, penetrate through the board surface, and release the wax particles from the surfactant coating. Countering this is the accelerated cooling effect of the surrounding air and the water contacting the surface during spraying. White areas represent the emulsion sitting in depressions on the surface (shown by the arrow). Shortly thereafter, the board surface appeared dry with no wax solution visible.

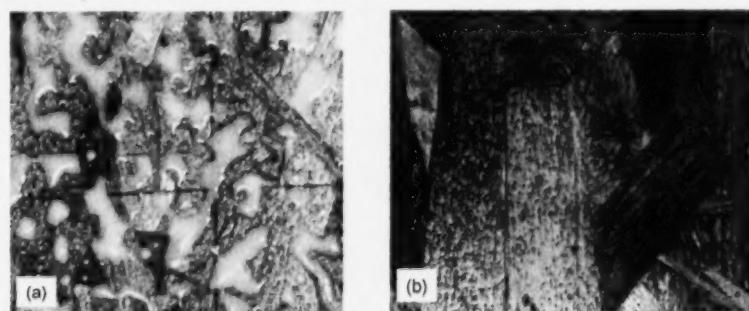


Figure 12. (a) Beading of the Cascowax emulsion on a hot board surface, and (b) the UW5F emulsion seeping into the hot board surface and filling crevices within a minute of spraying.

3.1.2 Thickness swell, length expansion, and water absorption

Table 4 summarizes the *p*-values at the α -level of 0.05 from the ANOVA models for thickness swell and water absorption at each soaking time. Table 5 summarizes the ANOVA model for thickness swelling and water absorption incorporating the soaking-time effect as a factor.

Table 4. Summary of *p*-value results from ANOVA models for thickness swell, water absorption at different soaking times, and length expansion after 24 h of soaking.

	Wax type	Concentration	Wax x conc.
2 h TS	0.012	<0.001	NS
2 h WA	0.012	<0.001	<0.001
6 h TS	<0.001	<0.001	<0.001
6 h WA	0.002	<0.001	<0.001
24 h TS	0.014	<0.001	0.006
24 h WA	NS	<0.001	0.001
48 h TS	0.022	NS	0.022
48 h WA	NS	0.005	0.005
24 h LE parallel	NS	NS	NS
24 h LE perp.	NS	NS	NS

NS denotes no significant effect at $\alpha \leq 0.05$.

TS: thickness swell; WA: water absorption; LE: length expansion

Table 5. Summary of results from ANOVA model for thickness swell and water absorption incorporating soaking time as a factor.

	TS	WA
Wax	0.008	NS
Time	<0.001	<0.001
Wax x time	NS	NS
Concentration	<0.001	<0.001
Wax x concentration	<0.001	<0.001
Concentration x time	NS	0.004
Wax x concentration x time	NS	0.033

Average thickness swell and water absorption values were plotted as ratios of original dimensions and weight from the ANOVA models (Figure 13).

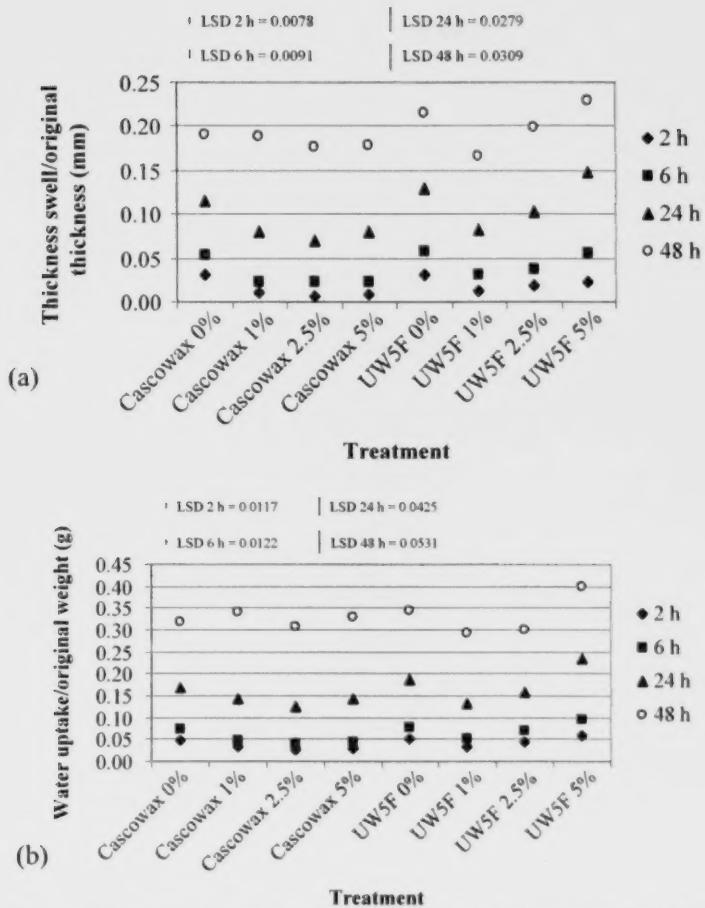


Figure 13. (a) Thickness swelling, and (b) water absorption for OSB treated with wax emulsions at 2-h, 6-h, 24-h, and 48-h soaking times. Least significant difference bars for each soaking time are shown above to facilitate comparison of means. The soaking times are separate variables, each with their own least significant difference bar for comparison of means.

Tables 6 and 7 provide average percent thickness swell and water absorption values for board replicates 1 to 6.

Table 6. Average thickness swell values (%) for OSB treated with wax emulsions.

Treatment	2 h	6 h	24 h	48 h
Cascowax 0%	2.98	5.25	11.49	19.05
Cascowax 1%	0.93	2.22	8.03	18.95
Cascowax 2.5%	0.65	2.30	6.99	17.53
Cascowax 5%	0.80	2.18	8.00	17.81
UW5F 0%	3.11	5.67	12.90	21.49
UW5F 1%	1.30	3.15	8.18	16.64
UW5F 2.5%	1.79	3.67	10.22	19.89
UW5F 5%	2.25	4.83	14.78	23.04

Table 7. Average water absorption values (%) for OSB treated with wax emulsions.

Treatment	2 h	6 h	24 h	48 h
Wax A 0%	4.89	7.30	16.83	31.93
Wax A 1%	3.36	4.59	14.25	34.12
Wax A 2.5%	2.62	3.95	12.37	30.69
Wax A 5%	2.91	4.46	14.17	33.02
Wax B 0%	4.98	7.83	18.54	34.29
Wax B 1%	3.47	5.15	13.10	29.41
Wax B 2.5%	4.52	6.93	15.73	30.15
Wax B 5%	5.79	8.52	23.26	39.73

For soaking durations of 24 h or less, the effects of wax type and concentration on thickness swelling and water absorption were significant ($p = 0.01$ or less). Note also that the pattern of response to wax type and concentration remained fairly consistent regardless of soaking time. Even though the 24 h thickness swell of the untreated control boards were below the Canadian Standards Association's maximum of 15% (CSA 1993), Figure 13 indicates that the most effective wax-emulsion solution for imparting greater short-term (less than about 6 h) resistance to thickness swell was the Cascowax solution at 2.5% solids content, whereas for longer-term moisture resistance (48 h or more), the UW5F emulsion solution at 1% solids content was most effective. Boards treated with UW5F solution at 1% or Cascowax solution at 2.5% solids content had significantly lower thickness swelling than the untreated controls at all soaking times.

Increasing the concentration of wax emulsion to 5% had no additional beneficial effect on water resistance of boards and, in fact, exacerbated water uptake and thickness swelling when samples were soaked for the longer time period of 48 h. Thickness swell responses after 24 and 48 h for boards treated with the UW5F wax emulsion at 5% solids content were higher than those for the untreated control boards (Figure 13a and Table 6).

3.1.3 Contact angle and droplet absorption

Some qualitative differences in the ability of water to soak into the surface of wax-treated or untreated OSB surfaces can be seen in Figure 14. These differences were quantified using contact angles.

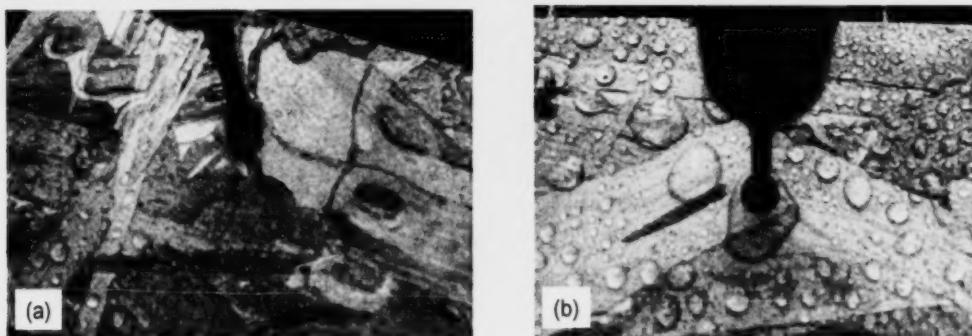


Figure 14. Appearance of (a) control and (b) surface treated with 2.5% Cascowax immediately after wetting. The dark object in the photograph is a linear surface height transducer.

Table 8 provides mean initial contact angles and time to 50° for each board treatment. A longer time taken for a droplet to seep into the surface and reduce in contact angle to 50° indicates a surface more resistant to water penetration. Both wax types at 1% produced a similar or slightly more hydrophobic surface in terms of initial contact angle than that of the untreated board surface.

The main effect of wax addition was on time taken for the droplet to penetrate the surface. The addition of Cascowax almost doubled the time taken for the droplet to recede to an angle of 50° compared with the control, whereas for UW5F at 1%, droplet behaviour was not very different from the control. This suggests that short-term behaviour of small water droplets on the surface may be only partly indicative of the longer-term capacity of the surface treatment to restrict thickness swelling, especially when there are interactions between the coating and the water that take place beyond the time that a droplet sits on the surface (which is normally less than 1 hour). The other phenomenon affecting thickness swelling not reflected in contact angle measurements is the flow of the wax-emulsion solution into the surface voids. The most striking result from the contact angle measurements was that the addition of UW5F at 5% produced a distinctly more wettable surface than the untreated surface, with water droplets spreading and penetrating the surface within seconds of application. This observation probably contributed to the high water absorption of boards that were treated with UW5F at 5% (Table 8).

Table 8 Mean initial contact angle (C_i), and time taken for a droplet to reduce to 50° for control and wax-treated OSB surfaces.

	C_i (degrees)	Time to 50° (s)
Control (no wax treatment)	108	996
Cascowax 1%	111	1730
Cascowax 5%	104	1669
UW5F 1%	109	740
UW5F 5%	102	36

The other noticeable feature about the behaviour of water droplets placed on the surface of OSB was the degree of variability. One source of variation was the distribution of wax over the surface, especially in the case of the Cascowax, which had the tendency to bead even on very hot board surfaces, resulting in an uneven spread of wax over the surface. Another factor affecting the initial contact angle and rate of change in contact angle was the type of strand present on the surface and the amount of resin on it. At this time, there are insufficient contact angle measurements per sample to account for such variation and further measurements are required. Further contact angle measurements are required to address how wood type present in the surface of OSB sampled in this study, i.e. aspen, pine heartwood, sound pine sapwood or blue-stained pine sapwood, influences contact angle and thickness swelling of boards.

3.1.4 Relationship between water absorption and thickness swell

Another finding from this work suggests that the type of wax-emulsion solution used to treat the surface may change the normally strong positive correlation between water uptake by wood or composites and its thickness swell. Note in Tables 6 and 7 that, in the case of the UW5F at short soaking times (2 h and 6 h), boards with a high wax level (5%) had higher water absorption but lower thickness swelling than the controls had, whereas the Cascowax solution effectively reduced both water absorption and thickness swelling compared to untreated controls. One possible explanation for this observation may be related to how much easier the UW5F solutions were to spread and penetrate the board surface than the Cascowax solutions were. It is well known that a penetrating water-based solution results in the resumption of almost the original shape of viscoelastically compressed wood cells in composite boards known as *spring back*. Once the wood cell walls are saturated with water and swollen to reform the cell lumens, the amount of void space into which water can penetrate without contributing to thickness swell is increased significantly.

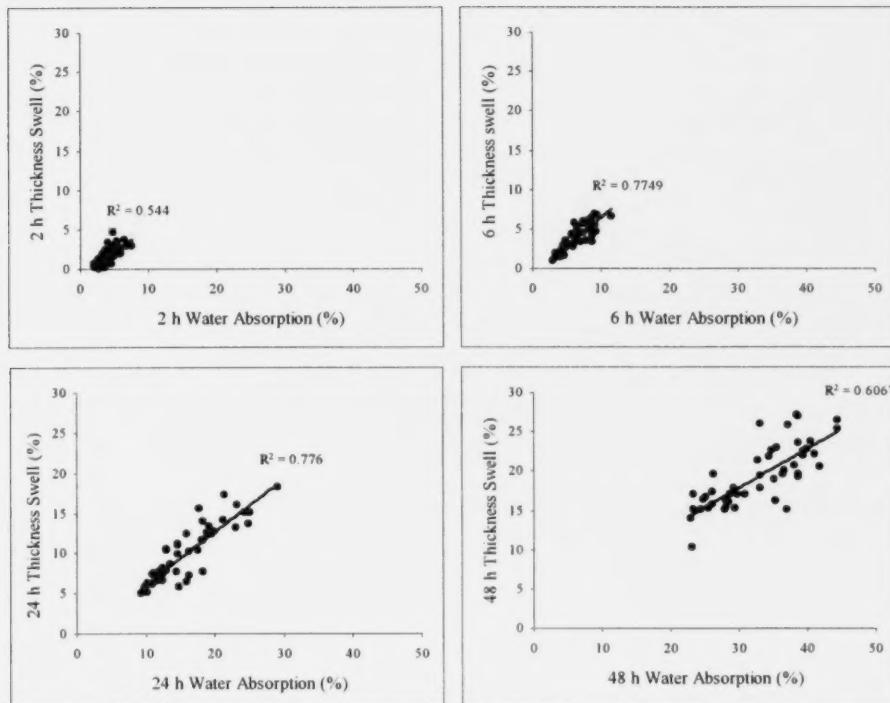


Figure 15. The relationship between water absorption and thickness swell for all OSB specimens.

Figure 15 indicates that soaking time strongly affected the relationship between water uptake by boards and their thickness swelling. This was evident from plotting thickness swelling against water absorption for specimens at each of the soaking times. There was a loose positive correlation ($r^2 = 0.54$) between water absorption and thickness swelling after 2 h of soaking, which improved when samples had been soaked for 24 h. This supports the idea that when OSB first comes in contact with water, the water penetrates into any easily accessible interstitial void spaces between strands first, where it does not directly cause thickness swelling (Wu and Piao 1999). The water takes longer to be adsorbed into cell-wall matrices, where it results in cell-wall expansion and the cells regaining their shape, thereby causing thickness swelling. The highest degree of correlation between water uptake and thickness swelling was after 24 h of soaking, after which the correlation diminished again. It is known that, with additional soaking time, swelling of the strands in OSB opens up more voids within strands (i.e., cell lumens, ray spaces) and strand bonds are ruptured further. This opens paths for water to penetrate, but does not contribute to more thickness swelling (Winistorfer and Wu 1996).

3.1.5 Swelling and drying behaviour of oriented strand board

The swelling behaviour of the OSB surface under a range of different wetting regimes is shown in Figures 16. Figure 16a shows the surface swelling or shrinkage response after simulated light rain showers over a period of 5 h, during which time the water beaded on the board surface. Figure 16b shows surface swelling and shrinkage response to complete inundation over a period of 5 h, followed by drying, and Figure 16c shows the swelling response of the surface after six days of complete immersion in water.

From all the types of wetting, Cascowax at 2.5% or 5% and UW5F emulsion at 1% delayed the surface-swelling response compared to that of controls or boards treated with the higher loading

of UW5F emulsion. From the samples that were wetted then allowed to dry for a couple of days, it is clear that if the surface swells to a large extent, it will remain in a much more swollen state after drying than when thickness swelling is restricted by an appropriate wax-emulsion treatment.

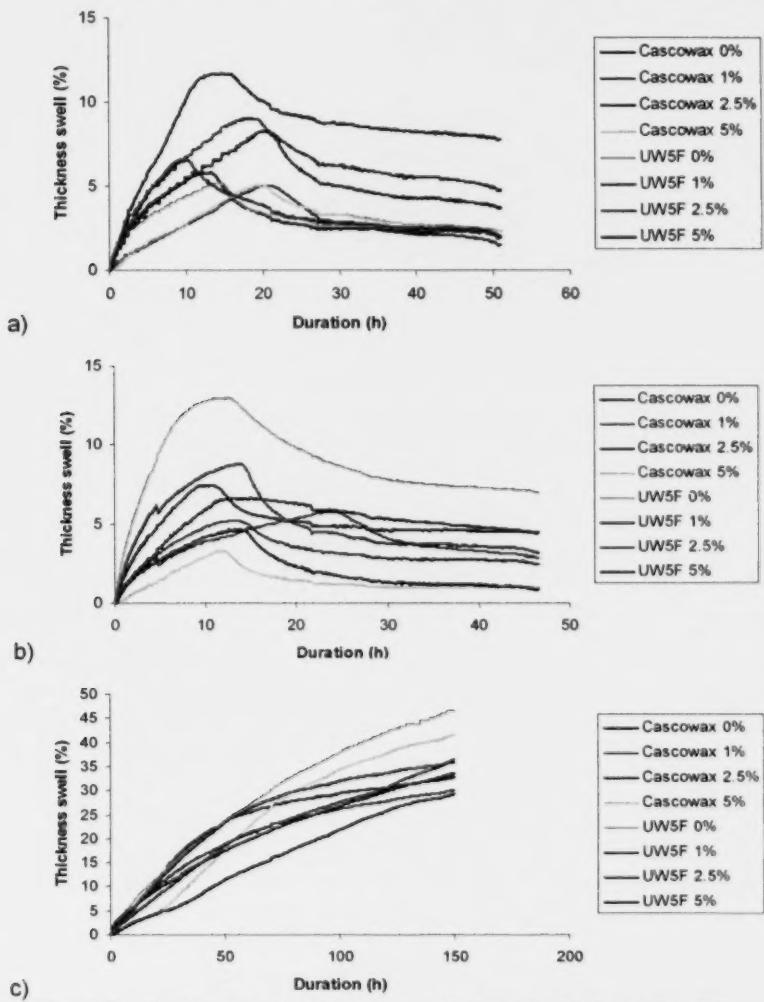


Figure 16. (a) Swellometer graphs for replicate 1, simulated light wetting followed by drying; (b) swellometer graphs for replicate 2, immersion for 5 h followed by draining and drying; (c) swellometer graphs for replicate 5, immersion for six days

Figure 16c shows that even after six days of immersion, thickness swelling continued to increase at a steady rate up to almost 50% of the original surface height above the mid-plane of the sample (the bottom surface was completely sealed). Research by Winstorfer and Wu (1996) showed that thickness swell of compressed discrete layers of OSB reached a maximum of about 25% after 8 h to 10 h of soaking before levelling off. For comparison, layers of plywood undergo between 6% and 12% thickness swell from oven dry to full saturation. The results here strongly indicate the time-delayed cumulative effect of layer-thickness swelling as water progressively makes its way into cell-wall matrices in the inner layers of OSB.

The effects of time-delayed thickness swelling on the recovery of shape after drying are shown below in Figures 17 and 18. Figures 17a and b show short-term water loss over 21 days, whereas Figures 18a and b show reduction in weight and thickness over a longer (40-day) drying period, followed by oven-drying.

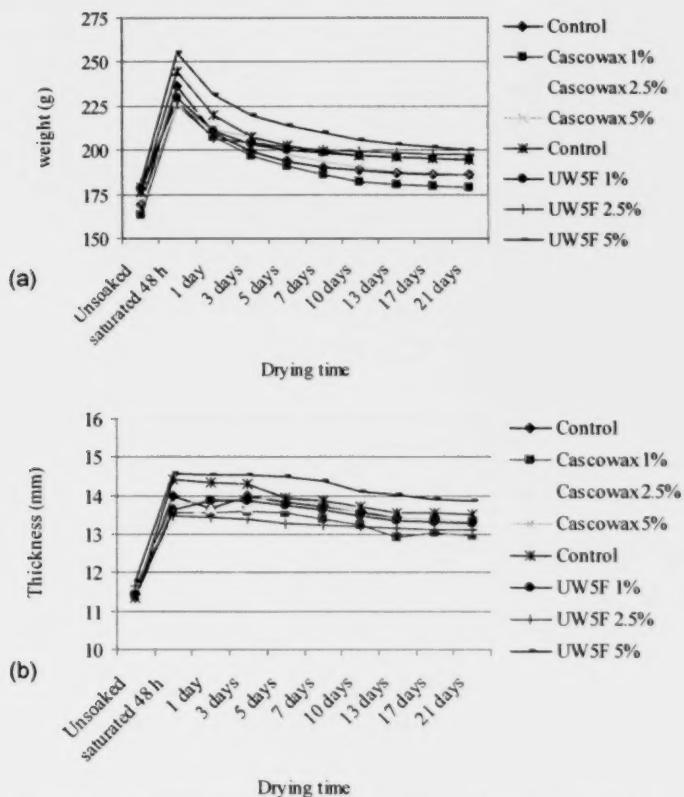


Figure 17. (a) Reduction in sample weight and (b) thickness after 48 h of soaking with a controlled drying time at 20°C and 65% RH, replicate 5, 21-day drying time

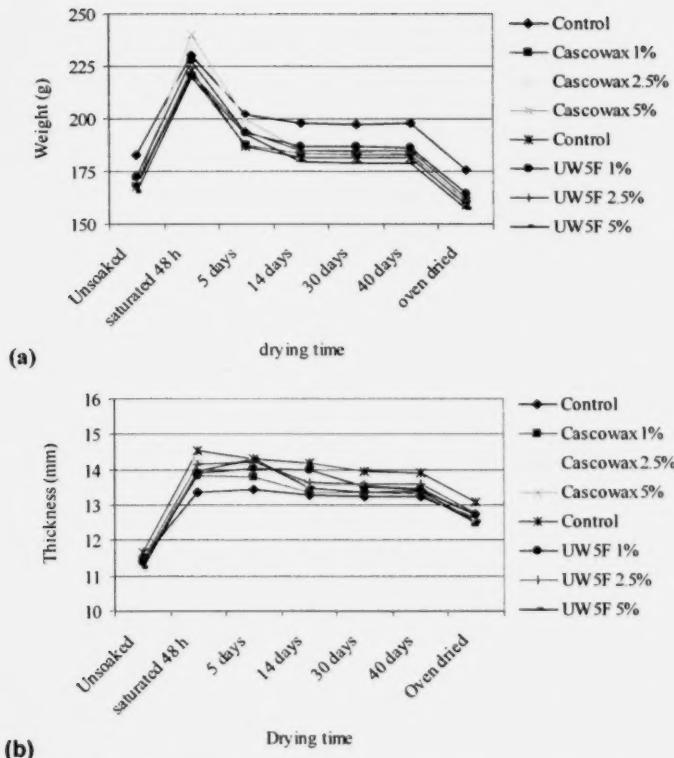


Figure 18. (a) Reduction in sample weight and (b) thickness after 48 h of soaking with a controlled drying time at 20° C and 65% RH, replicate 1, 40-day drying time.

It was thought that the emulsion wax might slow the loss of water from OSB during drying. This did not appear to occur. In the cases where samples absorbed more water and swelled more, they tended to retain their higher moisture contents and thickness swelling after a given period of drying, as shown in Figure 16 and discussed. This can be seen in the case of the UW5F emulsions applied at 5% in Figure 17. The most striking result from the reconditioning of treated-then-soaked boards was that, although they equilibrated in weight fairly rapidly with conditioning (i.e., after about five days), they retained their swollen state over a much longer time frame. With oven-drying, the boards remained thicker than they were before soaking. This is termed the *non-recoverable thickness swelling*—the ratio of the oven-dry thickness of the board after soaking and swelling to the oven-dry thickness of the board before it was exposed to water. Average non-recoverable thickness swelling was 13.25%.

3.1.6 Linear expansion

Linear expansion values after 24 h of soaking for specimens were very small (mostly less than 0.1-mm expansion after 24-h immersion). There was no significant effect of wax type or concentration on linear expansion (Table 4). The average values for linear expansion (pooled across wax type and concentration) were as follows: parallel-to-strand: 0.06 mm; perpendicular-to-strand: 0.1 mm. This was expected and accords with the rheological behaviour of solid wood, whereby its volumetric shrinkage and swelling is higher in the transverse directions (i.e., the tangential and radial directions) than it is in the longitudinal direction.

3.2 Experiment 2: Custom-Made Wax Emulsion Types

3.2.1 Surface hydrophobicity after treatment with wax emulsions

Table 9 lists the average surface hydrophobicity, defined as the initial static contact angle (C_i), and the time taken for the droplet to recede into the surface and reduce to a contact angle of 50°, for each wax type, commercial emulsion and water control (no treatment), as well as the surface of unsprayed OSB (control). A feature of OSB treated with water-based emulsions is some localised swelling and roughening of the board surface as the surface stands absorb water from the treatment. This was exacerbated by having to treat the surface while it is hot so as to get an even spread of treatment.

Table 9. Mean contact angle (C_i), and time taken for a droplet to reduce to 50° for controls and wax-treated OSB surfaces.

	C_i (degrees)	Time to 50° (min)
No treatment control	107.0	16.0
water only	108.0	16.6
UW5F 1%	109.0	12.3
Cascowax 1%	111.0	28.8
Slackwax 1%	104.1	4.7
Soywax 1%	87.5	4.2
Beeswax 1%	94.8	3.5
Carnauba wax 1%	109.7	10.8

The initial contact angle was highest for emulsion-wax types Cascowax and Carnauba wax. These are made from hard Fischer-Tropsh and palm wax, respectively, and are expected to have a greater degree of hydrophobicity. The lowest average contact angles and residence time of droplets on the treated board surface were for the soy wax, beeswax, and slack wax, all of which are soft, less hydrophobic waxes. The most notable finding was that application of water-based emulsion waxes to hot board surfaces decreased droplet-residence times compared to that of the unadulterated OSB surface. The only exception to this was the Cascowax emulsion, which increased the droplet-residence time to almost 30 min compared to 16 min for no wax application. It is thought that the pre-swelling and roughening of the surface strands induced by spraying a water-based liquid onto the hot surface may cause water droplets to penetrate the surface more easily during contact angle testing. However, all of the emulsion-wax treatments were water-based and were applied to a hot board surface. Each of the treatments causes surface pre-swelling and roughening to some extent. The commercial Cascowax formulation differs from the others in that it was the most difficult to spread over the surface, and its surfactant system is completely unknown. The surfactant system for the commercial UW5F formulation is also proprietary. However, for all the other wax emulsions, the surfactant system was the same. This suggests that the surfactant system may be responsible in part for reducing droplet-residence times on board surfaces.

3.2.2 Thickness swell and water absorption of OSB treated with custom-wax emulsions

Results indicated that applying any of the custom-made wax emulsions to OSB, and drying them, tends to increase the boards' susceptibility to water absorption and thickness swell when board samples were immersed in water (Tables 10 and 11). It was hoped that hydrophobic particles in the water-based emulsions would effectively counteract any effect of the water or the surfactant in the application; however, results suggest this did not occur. In terms of reducing board susceptibility to further water absorption and thickness swell, the only emulsion types that reduced thickness swell were the commercial products tailored for wood-preserved systems

(UW5F) and the emulsion sold for use with resin blending to improve the dimensional stability of composite boards such as OSB and particleboard. The best wax emulsions for reducing the 24-h and 48-h thickness swell of OSB were the Cascowax (which was difficult to apply as a water-based solution) and UW5F formulations designed to enhance the dimensional stability of preservative-treated wood. These produced a small reduction in 24-h thickness swell from over 10% for untreated boards to about 8%. The 4-h thickness swell increased slightly for emulsion-treated boards compared to untreated boards. The rest of the wax emulsions exacerbated thickness swelling and water absorption compared to untreated boards and those treated with a control solution of water.

Table 10. Average thickness swell (%) after 2 h, 6 h, 24 h and 48 h for OSB treated with wax emulsions

	2h	6h	24h	48h
No treatment	2.67	5.05	10.60	15.66
Control (water only)	3.04	5.46	12.20	20.27
UW5F 1%	1.3	3.15	8.18	16.64
Cascowax 1%	0.93	2.22	8.03	18.95
Slackwax 1%	4.76	9.27	17.65	20.12
Soywax 1%	3.78	7.13	16.33	21.32
Beeswax 1%	4.14	8.44	16.29	21.08
Carnauba wax 1%	4.09	8.46	15.85	21.41

Table 11 Average water absorption (%) after 2 h, 6 h, 24 h and 48 h for OSB treated with wax emulsions.

	2h	6h	24h	48h
No treatment	3.65	6.59	13.97	21.43
Control (water only)	4.93	7.56	17.68	35.83
UW5F 1%	3.47	5.15	13.10	29.41
Cascowax 1%	3.36	4.59	14.25	34.12
Slackwax 1%	12.52	20.90	34.38	44.25
Soywax 1%	8.22	13.96	28.09	39.42
Beeswax 1%	10.25	18.44	34.71	44.94
Carnauba wax 1%	8.79	14.00	25.85	35.79

Average 24-h thickness swell of boards treated with the test emulsions was 16.5%—i.e., more than twice what it would be with a commercial emulsion. When swelling was continuously monitored over time, the wax treatments were observed to accelerate OSB thickness swelling compared to the swelling behaviour of untreated OSB board (Figure 19). This effect was most pronounced with the slack wax emulsion: this was the softest, oiliest and least hydrophobic of all the waxes tested.

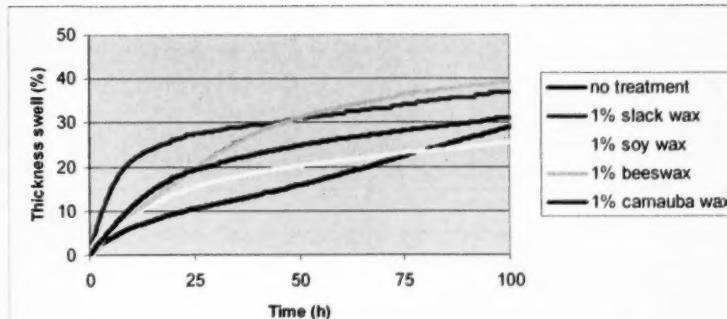


Figure 19. Thickness swell measured by swellometer for OSB samples treated with different water-based wax emulsions.

Two possible reasons may account for the increased water absorption and thickness swelling that resulted from treating the hot surface of OSB with the custom-made water-based wax-emulsion solutions. The first reason may be a possible disruption of the heat-sealed surface of OSB that results from the hot-pressing process occurred; the second reason may be the presence of hydrophilic surfactant in the wax emulsions. The contact angle results suggest something in the noncommercial emulsions contributes to increased water penetration and thickness swelling. Droplet contact angle and residence time on untreated OSB and water-treated OSB were similar at 107°–108° and approximately 16 min to recede to 50°. In contrast, the noncommercial wax emulsions reduced droplet-residence time to less than 10 min, and, in most cases, to less than 5 min.

3.2.3 Aspects of emulsion-wax application

The UW5F was easy to apply to board surfaces, possibly because greater surfactant activity broke up its surface tension and allowed it to spread over the heated surface. Our finding suggests that a wax-emulsion solution containing enough surfactant to enable it to spread and penetrate the surface of hot boards is desirable. An important reason why UW5F at 1% was more effective at reducing thickness swelling than the Cascowax was its ability to seep into the inter-strand voids on the surface (Figure 12b), where water percolates down into deeper board layers in the board. These depressions in the surface tend to collect more of the wax solution, which would help explain the 1% UW5F solution's greater effectiveness at restricting thickness swelling over a longer soaking period (48 h).

We had hypothesized that the addition of greater concentrations of wax might be a way to reduce OSB water uptake and thickness swelling, which is also the basis for the patent application by Racota (2007). However, it was found that increasing wax-emulsion solids content to 5% increased water uptake and thickness swell, most markedly in the case of the UW5F emulsion-wax formulation. Our findings are consistent with previously observed effects resulting from blending strands or flakes with emulsion wax at concentrations higher than about 1% on dimensional stability of OSB. Previous studies by Winistorfer et al. (1996) on wax addition during blending and prior to hot pressing show a strong wax-type-by-concentration interaction effect on OSB moisture resistance, and found 1% wax to be the optimal application rate. Those studies were unable to identify any peculiar characteristic of the wax itself, i.e., molecular weight or oil content, as being responsible for differences in wax performance in restricting OSB thickness swelling, but wax concentration above about 1% resulted in increased thickness swelling, which was attributed to interference by the wax with resin-bond formation during pressing.

Increasing thickness swell at higher rates of wax addition cannot be attributed to interference with bond formation, and is therefore more likely to be linked to surfactant constituents in the emulsion formulation. The greater swelling effect of UW5F at higher concentrations is consistent with the more effective wetting and surface penetration of this wax emulsion on the board surface, indicating greater surfactant content. Surfactants contain both hydrophobic and hydrophilic groups; it appears that when an emulsion-wax formulation with more surfactant is added to board surfaces at higher concentrations, the effect of the greater amounts of hydrophilic groups in drawing water into the surface outweighs the hydrophobic effect of the wax.

The surfactant effect is evident from increased ease of droplet penetration. Figure 19 illustrates how the continuous thickness swell pattern for untreated board was fairly linear, whereas swelling of the emulsion-treated boards was very steep over the first 24 h, and then continued at a reduced rate. The surfactant used to make the non-commercial wax emulsions was of a different type (and, likely, quantity) than that used to make the commercial (proprietary) emulsions in which the surfactant type and quantity were unknown, and may have resulted in a more hydrophilic surface. In Experiment 1, the increased thickness swell with increasing concentration of commercial emulsion is believed to have been caused by the increasing quantity of hydrophilic surfactant being added to the surface, counteracting the effect of the wax and increasing the water absorption and thickness swell.

Another drawback of having to apply a water-based spray to a hot board surface is that the water is absorbed into the board to some extent, resulting in some preliminary swelling and roughening of the surface. This may also help explain the rapid early swelling of the boards treated with the water-based wax emulsions (Figure 19). One possible cause of this is that the pores in the surface strands are partially opened up by the exposure to water, and this allows the rapid early swelling of the surface strands. After these had fully swollen, it took longer for water to penetrate into deeper strands.

Another major factor that reduces the longer-term moisture-resisting capacity of wax-emulsion treatments for wood and composites is a phenomenon known as preferential wetting. The cellulose and hemicellulose affinity for water molecules (i.e., bond energy) is higher than that of the wax or oil of a water-repellent treatment. This results in the progressive displacement of the wax coating over time and reduces its effectiveness (Borgin 1961; Borgin and Corbett 1970). According to Borgin and Corbett (1969), the only really effective moisture-protection systems for wood-based materials are those that can deeply penetrate through the surface of a piece of wood to inner layers and are not displaced by water molecules. A water-proofing agent that is covalently fixed to wood-cell walls would also have greater longevity.

It is important to note also that the effectiveness of wax emulsions as a treatment for OSB is further limited by the distinctive features of the OSB surface that differ from surface features of solid wood. An OSB surface is much more hydrophobic than the surface of fresh wood strands, because of the combination of the wax added during blending and the heat treatment of the surface during pressing in OSB manufacturing. The natural short-term moisture resistance of the surface of the control (no wax treatment) specimens could be seen in Figure 14a, whereby droplets and pools of water remained on the surface after wetting. This indicates that a water-based wax-emulsion solution would not seep into the surface strands as easily as it would if used to treat solid wood. In addition, the formerly open capillary structure of the wood strands in the surface layers of OSB are highly compressed during hot pressing, and the ability of the wax particles to quickly penetrate the surface strands is reduced compared to its penetration of a solid wood surface.

3.3 Experiment 3: Oil-Based Coatings Containing Wax

To try to overcome the challenges experienced when applying water-based wax emulsions to OSB, an alternative non-water-based coating system, based on cheap and naturally derived linseed oil, was investigated alongside a range of commercially available coatings systems commonly used to protect solid wood from moisture. All coating types were assessed based on a one-time (i.e., one coat) application to boards, because any post-pressing treatment of OSB would take place in one pass. One of the acrylic wood clear coatings (Diamond Varathane) was applied by brush at the manufacturer's recommended four coats with a day's drying between each, to serve as a comparison.

3.3.1 Coating consistency and application to hot or cold board surfaces and coating-setting times

Applying commercial boiled linseed oil, mineral oil, and other commercial protective finishes for wood, including shellac, urethane, and acrylic, was easier than applying water-based emulsion waxes or resin. The oil-based coatings formed a continuous film over the board surface, even when the board surface was not heated. Boiled linseed oil is a major base for oil-based paints and polishes for wood because it is a *drying oil* that cross-links as it cures and leaves no oily or greasy residue on the surface. The application of the clear mineral oil also resulted in a non-greasy surface. The problem of the coating pre-swelling the surface strands, causing an uneven surface once dry, did not seem to occur with application of oils or the reference coatings.

When applied to a hot board surface, the surface tension of the linseed oil reduced rapidly, and it penetrated into the board surface quickly and easily. On a cold board surface, the oil tended to seep into the surface strands in some areas or remain on the top where it formed a hard layer. The ability of the oil to seep into the surface strands was originally thought to be potentially beneficial for reducing OSB thickness swelling, as it may create a cross-linked network extending deeper into the subsurface. The effectiveness of this technique for reducing thickness swell is reported in Section 3.3.3.2.

Linseed oil was also tested in combination with a variety of common industrial and craft waxes, most of which were also tested in the emulsified form (see Sections 3.1 and 3.2). Detracting from the practicality of applying hydrophobic waxes (especially paraffin) mixed in with the oil is the necessity for the oil-wax mixture to be heated prior to application of the treatment to the board surface. As the mixture contacted the cooler board surface, it would begin to stiffen to a paste—in the case of the paraffin mix, almost immediately. This consistency disappeared when the samples were placed in the oven for heat setting and, in some areas, the coating disappeared from the surface entirely.

3.3.2 Contact angle measurements

3.3.2.1 Reference coatings

Contrary to expectations, several of the reference coatings—commercial finishes for wooden items such as shellac, urethane, acrylic and the lam-print roller-coater paint—made the surface of OSB more hydrophilic than it normally is without any surface treatment (Table 12). Commercial shellac, urethane coating, and acrylic reduced the contact angle from 107° for an untreated OSB surface to 71°, 70°, and 56°, respectively, and made only a small difference to droplet-spreading and -penetration time. Of particular note was the strong effect of the acrylic coating on droplet-residence time, reducing it from an average about 16 min for untreated OSB to about 10 s, indicating that the surface had become much more hydrophilic. In contrast, applying a strongly hydrophobic substance such as a siloxane-based cotton-fabric protector increased the water-beading effect and the droplet-residence time on the surface. In this instance, the average contact angle was 126° and the droplet-residence time was 83 min; that is, the droplets remained on the surface until they evaporated.

Table 12. Average droplet contact angles (C_i) and the time taken for a droplet to recede to a contact angle of 50° for reference coatings

	Contact angle (C_i°)	Time to 50° (mins)
Untreated OSB surface	107	16
1% UW5F	116	12
Shellac	71	25
Urethane	70	22
Acrylic	56	0.15
Stainguard Water Rep.	126	83
White lam-print	76	1
Mineral oil	94	17

Each mean is the average of 10 contact angle runs

3.3.2.2 Linseed oil-wax coatings

The average contact angles and droplet-residence times for various types of linseed oil and wax-based coatings are given in Table 13. The initial contact angle for surfaces treated with linseed oil or linseed oil-wax mixtures were not high compared to those for the untreated OSB surface or the surface treated with a water-repellent wax emulsion. Uncured linseed oil has some hydrophilic components and therefore will not form a contact angle of above 90° with water (Borgin 1961). The increased contact angle for the polymerized linseed oil coating suggests that it increased its hydrophobicity after hardening. Contact angles for linseed oil-based treatments were also higher than for boards treated with commercial protective coatings for wood, such as shellac or synthetic acrylic-based or urethane-based protective finishes sold for painting or spraying onto raw wood (Table 13 vs Table 12).

Table 13. Average droplet contact angles (C_i) and the time taken for a droplet to recede to a contact angle of 50° for linseed oil and linseed oil-wax coatings.

	Contact angle (C_i°)	Time to 50° (mins)
Linseed oil	103	50
Linseed oil + Soy wax	107	60
Linseed oil + Carnauba wax	108	55
Linseed oil + Beeswax	107	59
Linseed oil + Paraffin wax	97	53

Each mean is the average of 10 contact angle runs.

The most notable feature of droplet behaviour on the surfaces treated with linseed oil and especially the linseed oil-wax mixtures was the greatly extended droplet-residence time, close to one hour compared to less than about 20 min in the case of the untreated or wax-emulsion-treated surfaces and most of the commercial reference coatings. The droplets did not penetrate through the skin of the hardened coating; instead, they remained on the surface and only reduced in contact angle as they slowly spread and evaporated over the course of about one hour. Because of this, it was expected that the drying oil-based treatments would have a greater effect on restricting water penetration into OSB surface than did wax-emulsion treatments or several of the common commercial finishes for wood that had smaller contact angles and shorter droplet-residence times.

3.3.3 Thickness swell and water absorption

3.3.3.1 Commercial and comparative coatings

None of the commercial coatings applied as one coat was capable of improving OSB resistance to thickness swell and water absorption (Tables 14 and 15; Figure 20). When applied at the recommended four coats, the Varathane product for outdoor protection for solid wood was effective at restricting water uptake and thickness swell, but this method would be expensive and

impractical for OSB manufacturers because the amount of coats needed and time required to apply and dry them. After 24 h and 48 h of continuous exposure to water, there was evidence of localised swelling of surface strands and telegraphing through the varathane coating. One coat of the shellac and the stainguard provided a small measure of short-term resistance to water uptake compared to the other treatments. The shellac coating and, to a lesser extent, the acrylic coating went white after exposure to water. The White lam-print paint behaved like a paint lacking elastic properties and was susceptible to cracking along the raised edges of swollen strands on the board surface. Being a hot-compressed composite formed from disparate strands, OSB has a thickness swelling two to four times that of plywood (Figure 20).

Table 14. ASTM-standard thickness swell results (%) for OSB treated with various types of commercial and other surface treatments.

	2h	6h	24h	48h
No treatment	2.26	4.98	10.61	15.69
1% UW5F	1.3	3.15	8.18	16.64
Shellac	2.26	6.24	14.62	23.51
Urethane	2.96	6.32	15.17	20.55
Varathane 4c	0.11	0.84	3.64	7.73
Acrylic	3.87	8.46	17.87	24.76
Mineral oil	10.45	11.33	22.01	26.15
White lam-print	4.04	6.85	11.66	17.71
Stainguard	2.45	5.72	12.54	21.4

Table 15. ASTM-standard water absorption results (%) for OSB treated with various types of commercial and other surface treatments.

	2h	6h	24h	48h
No treatment	3.65	6.59	13.97	21.43
1% UW5F	3.47	5.15	13.10	29.41
Shellac	2.79	5.63	16.04	26.74
Urethane	4.46	8.71	19.09	30.06
Varathane 4c	1.31	2.27	5.58	11.20
Acrylic	7.46	13.43	25.33	34.61
Mineral oil	7.90	13.09	23.91	34.38
White lam-print	6.01	9.23	16.05	22.15
Stainguard	3.58	6.31	14.80	23.71

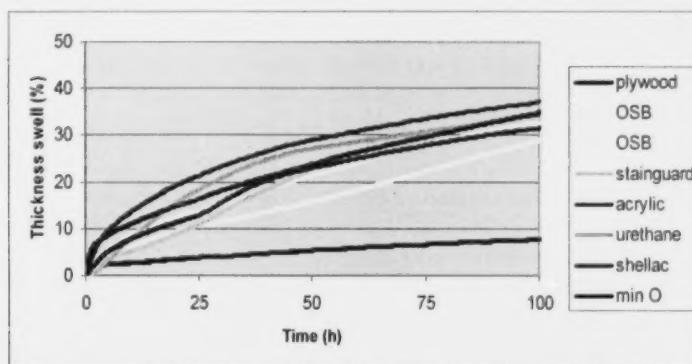


Figure 20. Surface-swell response of the 7.6-cm x 12.7-cm swellometer OSB specimens, uncoated or coated on the top surfaces with reference coatings and kept underwater for up to 100 h. Results for plywood are shown for comparison. min O=mineral oil.

3.3.3.2 Linseed oil plus dissolved waxes

Some of the linseed oil-based surface treatments imparted short-term (less than 24 h) resistance to water exposure compared to untreated boards (Tables 16 and 17, and Figures 21 and 22). The controls (no treatment) boards swelled by an average 2.7% of their original thickness after 2 h of soaking and by about 5% after 6 h. After 2 h of continuous exposure to water, all the treatment groups—wax emulsion, linseed oil and linseed oil plus wax—significantly reduced thickness swell, but not water absorption (although the effect of the linseed oil plus wax on reducing water absorption was significant at $p<0.05$), suggesting that water was making its way into void spaces but not into the strands themselves. The linseed oil treatment reduced 2-h thickness swell (but not 24 h), whereas the oil and wax mixtures were a much better treatment, reducing average 2-h thickness swell to around 0.9% and 6-h thickness swell to around 3% (Figure 21a).

Table 16. ASTM-standard thickness swell results (%) for OSB treated with linseed oil and linseed oil-wax treatments.

	2h	6h	24h	48h
No treatment	2.67	5.05	10.60	15.66
Linseed oil, hot	2.02	4.90	13.39	18.61
Linseed oil, cold, 1 coat	2.62	4.77	10.50	16.77
Linseed oil, cold, 2 coats	1.44	3.57	11.19	19.82
Linseed oil +soy wax	0.89	2.49	8.47	14.90
Linseed oil +beeswax	1.19	3.52	10.89	17.98
Linseed oil +carnauba w	0.86	3.08	8.38	13.66
Linseed oil +paraffin w	0.74	2.87	8.73	14.97

Table 17. ASTM-standard water absorption results (%) for OSB treated with linseed oil plus dissolved waxes.

	2h	6h	24h	48h
No treatment	3.65	6.59	13.97	21.43
Linseed oil, hot	3.99	7.87	19.30	28.98
Linseed oil, cold, 1 coat	2.62	4.77	10.50	16.77
Linseed oil, cold, 2 coats	1.44	3.57	11.19	19.82
Linseed oil +soy wax	2.12	4.86	13.53	22.63
Linseed oil +beeswax	2.38	4.97	15.42	25.80
Linseed oil +carnauba w	2.00	4.12	11.35	18.98
Linseed oil +paraffin w	1.63	3.70	11.92	20.79

Linseed oil on its own reduced its effectiveness after 24 h of exposure to water compared to the linseed oil-wax treatments (Figure 21b). Some of the linseed oil-wax treatments reduced 24 h thickness swell to less than half that of an untreated surface (Figure 28). After a longer period of exposure to water, there was less difference between the linseed oil-based coatings and the controls. The 24-h thickness swell for controls was around 10.6%; it was 8.3% for the linseed oil-wax treatments. Within 24 h, the linseed oil-wax coatings appeared to be less resistant to breakdown by water than did linseed oil alone.

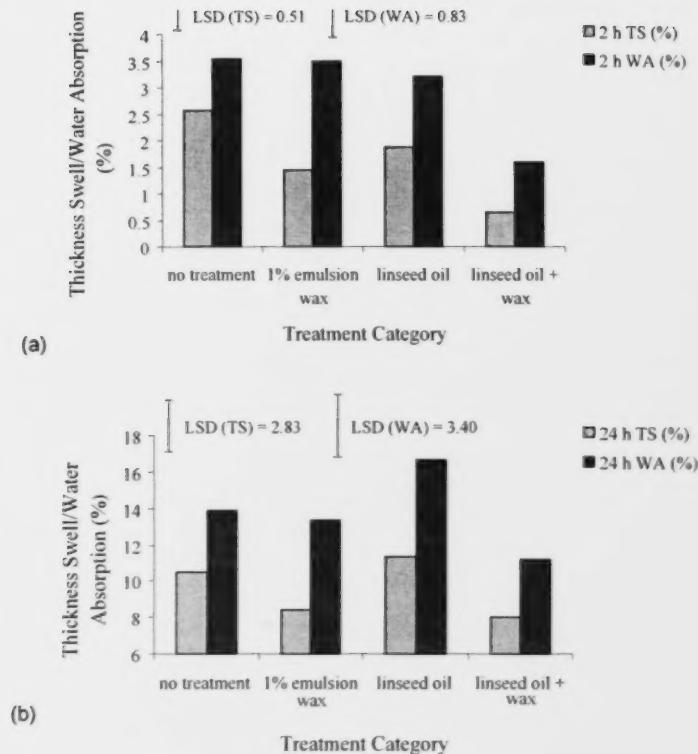


Figure 21. The effects of treatment grouped by coating-treatment type: (a) Average 2-h thickness swell and water absorption response of OSB after treatment; (b) Average 24-h thickness swell and water absorption response of OSB after treatment. Each mean is the average three replicate boards with two observations each.

However, by 48 h, the restraining effect on thickness swell had disappeared—in some cases, the linseed oil-treated or linseed oil-wax-treated boards swelled more than the untreated controls (Figure 22). The linseed oil-based coatings appeared to be broken down by water after a day or two of exposure; after 48 h of soaking, the difference between the treated and untreated OSB decreased as the rate of thickness swelling of the coated boards accelerated in many cases.

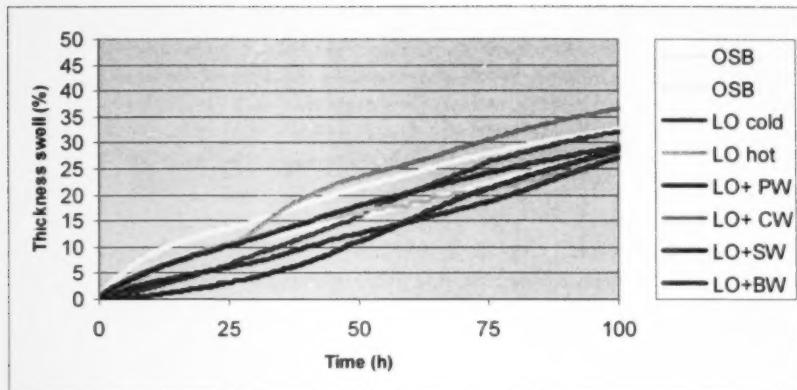


Figure 22. Continuous thickness swelling responses of OSB treated with linseed oil and linseed oil-wax coatings over 100 h.

Our results show that a combination of linseed oil and a more hydrophobic wax provided better protection from water uptake and swelling, especially in the short term, than no treatment, straight linseed oil, or a commercial emulsion wax. It was not possible to achieve a high degree of protection of OSB from water-induced swelling using any of the tested treatments; however, it is already established that protecting strand-based wood composites from moisture-induced swelling presents an enormous challenge (Feist 1982; Feist 1984). This is because the composites are comprised of heat-compressed disparate strands of low-density wood (i.e., lots of lumen space) in the surface layers that spring back close to their original thicknesses when they absorb water. Overall performance of even several coats of the most effective finishing systems decreases more quickly when applied to strand-based composites because of the very strong propensity for the surface strands to swell and delaminate.

One coat of each of the commercial wood and floor lacquers and finishes, especially the waterbased acrylics and urethanes, exacerbated OSB swelling response compared to the response of untreated OSB. These coatings can be effective finishes for wood, but must be applied as multiple coats with adequate drying time between applications to produce a smooth, blemish-free surface. The top layers must be free of blemishes and impervious to water. This, however, is not practical for an industrial post-manufacture OSB coating, where one-step application by high-speed roller coaters would be used. Furthermore, many water-based paints and coatings designed to repel temporary splashes of water chemically react with water and are broken down with continuous exposure to water (Smith 2005).

Coatings fall into two general categories: those that penetrate the wood substrate, such as wax-emulsion water repellents, oils and penetrating stains, and those that form a clear or opaque protective film over the surface, including most paints (Feist 1997; Lee et al. 2003). The advantages of penetrating coatings are that the protective agent penetrates deeper into the substrate, the wood can breathe, thereby retaining its original texture or colour, and the finish does not crack or peel like paint (Lee et al. 2003). The linseed oil finish is an example of a penetrating coating that was originally seen as being capable of providing good protection to OSB. However, the thickness swelling tests of the hot oil-treated surfaces found this was not the case. The resistance of treated OSB to water uptake and thickness swelling decreased when all the oil seeped into the surface. Specimens that had part or most of the surface covered in a skin of hardened, cross-linked oil better resisted water absorption and swelling; however, achieving a uniform, continuous skin of oil without applying more than two coats of oil was difficult: the coating remained on the surface in some areas and seeped into the surface strands and crevices in

other areas. Another factor affecting the formation of a continuous skin over the surface was the presence of surface crevices. Areas of the board that did not have a hardened skin over the top swelled noticeably more than those areas that did.

The results from the contact angle measurements indicate the likelihood of a coating restricting short-term (up to a few hours) moisture absorption, but did not indicate how long a coating would perform under prolonged exposure to water. The life of a droplet that does not penetrate the surface is one hour or so. It is evident from the thickness swell measurements that the linseed oil-based coatings take several hours to be degraded by water.

The water-repelling effect of hardened linseed oil is known to be short term. In a comprehensive study by Borgin (1961) on oils and waxes as water repellents for wood, linseed oil-impregnated wood did not withstand repeated exposure to wetting and drying without the oil being displaced or broken down by water. Those findings support results produced here showing that resistance of the linseed oil-treated boards to thickness swelling decreased after about two days of continuous exposure to water. A reason for the increased efficacy of the oil when it forms a hardened skin on the top may be that the thickened mass takes longer to be fully hydrolysed by water. If linseed oil-based treatments are applied to OSB, they should form a uniform hard skin over the top rather than seep into the surface strands.

A more effective treatment for restricting water uptake and thickness swell was a mixture of linseed oil and a small quantity of hydrophobic wax (carnauba wax, in particular) applied at a temperature just above the melting point of the wax. The addition of wax to the oil seemed to enhance the coatings' longevity, providing better resistance to thickness swell after 24 h and 48 h of continuous exposure to water (Figure 22). The greater effectiveness of this treatment may have been due to the fact that the application was applied more thickly and more of the coating stayed on the surface, and that the coating mix itself was more hydrophobic, as shown by the contact angle measurements. However, the oven curing of the application caused it to reduce in viscosity and seep into the board in many places, reducing the treatment's efficacy.

If a hardened, uniform glaze over surface strands can be created and maintained, the board's resistance to thickness swelling may be reduced.

3.4 Experiment 4: Surface Texturing and Void Filling

3.4.1 Glass Microspheres

The appearance and size of the different kinds of microspheres used in this study are shown in Figure 23. The most notable finding from the microscopy study of the materials was that the industrial-grade glass microspheres (Figure 23a) were prone to breakage into shards when attempts were made to prepare them for viewing under a glass cover slip (Figure 24). This was because of the thin-walled nature of the spheres, as evidenced by the very low bulk density of the material ($0.15\text{g}/\text{cm}^3$). The calibration-grade glass microspheres (Figure 23b to f) were mostly of uniform size and spherical shape, separating easily in water dispersion; although some were ill formed and fused.

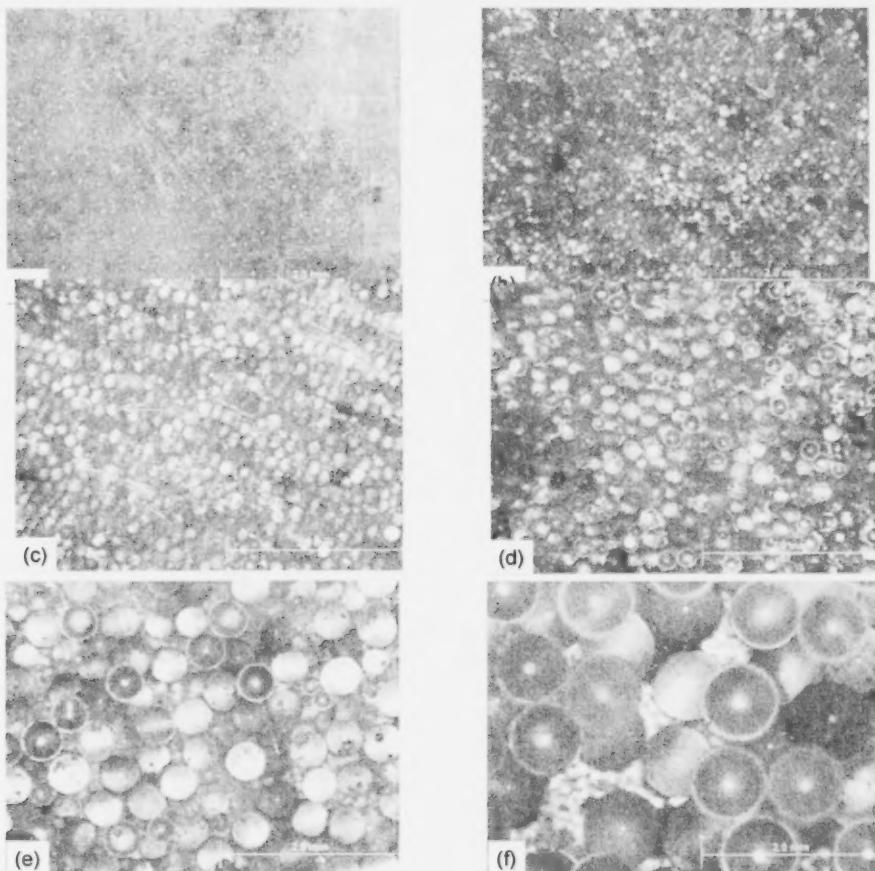


Figure 23. Appearance of glass microspheres glued to the surface of OSB under a light reflecting microscope at 10X magnification. Images portray microspheres of the following sizes: (a) industrial grade, 40–80 μm ; (b) calibration grade, 38–45 μm ; (c) 63–75 μm ; (d) 90–106 μm ; (e) 180–212 μm ; (f) 300–400 μm . The spheres are glued to a layer of melamine-resin adhesive on the board surface.

3.4.1.1 Distribution of microspheres on sprayed surfaces

The presence of microspheres on the surface of the spray-treated OSB samples was not visible to the naked eye but could be observed under a 4X light-reflecting optical microscope. Of the

smaller classes of microspheres used (100 µm or smaller), beads were visible on the surface of strands, and could be removed easily from the surface with a fine paintbrush, indicating that they had not adequately adhered to the surface of the boards. In the case of the larger-sized sphere classes, even at high solution loading, few, if any, beads were deposited onto the boards' surfaces by spraying, indicating that the larger sphere sizes (larger than 100 µm) are too large to be ejected from a spray nozzle. The most notable observation from the spraying of microsphere solutions was that, instead of seeing an even, continuous distribution of microspheres over the surface, the spheres tended to form in discrete clumps mostly on the top-most strands: some areas had no microspheres at all (Figure 24). The larger the microspheres, the fewer were deposited on the surface from the spray nozzle.

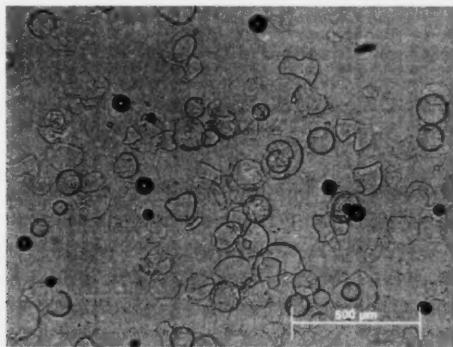


Figure 24. Thin-walled industrial microspheres under a glass cover slip, 40X magnification.

3.4.1.2 Distribution of microspheres adhered with melamine formaldehyde resin

The distribution of microspheres on the surface of the melamine adhesive layer was mostly continuous (Figure 29).

In most cases, microspheres were not one layer thick. The most difficult of the microsphere types to get a photographic recording of size and appearance using the camera-mounted light microscope were the industrial-grade spheres, due to their thin shells. The estimated spread rates of each type of microsphere per square metre of board surface using this method of application are provided in Table 18. Note that as the size of the microspheres increases, the weight applied increases.

Table 18. Estimated spread rates for microspheres of different sizes applied as a continuous layer over the surface of OSB.

Microsphere size	Weight on sample (g)	Spread rate g/m ²
40–80 µm Industrial grade	0.10	23
38–45 µm calibrating	0.23	52
63–75 µm calibrating	0.37	85
90–106 µm calibrating	0.80	181
180–212 µm calibrating	1.50	347
355–425 µm calibrating	3.00	689

3.4.1.3 Contact angles of oriented strand board surfaces treated with wax–microsphere solutions

Contrary to expectations, the addition of glass microspheres to the surface using the tested loadings and application technique did not increase the hydrophobicity of the board surface in terms of the static contact angle compared to the baseline hydrophobicity of the OSB surface or

that produced by adding a 1% wax-emulsion solution (Table 19). In fact, when microspheres were added at low or medium dosages, their presence decreased the droplet-residence time to below that of untreated OSB. The spot measurements of the droplet contact angle on the 15.2-cm x 15.2-cm-square OSB samples revealed a high degree of variability in droplet behaviour, in particular, in the time that the droplet remained on the surface before it spread and penetrated the surface. The coefficient of variation was high (often between 50% and 100%) for the time taken for the droplet contact angle to reduce to 50°, indicating that at some sampling points the droplet remained on the surface for longer, whereas at others it spread more easily. Possible reasons for this variability include the patchy and discontinuous distribution of microspheres on the surface, which could be seen under a light microscope at 4X magnification (Figure 25), and also the variability in the flake surfaces over the sample cross section.

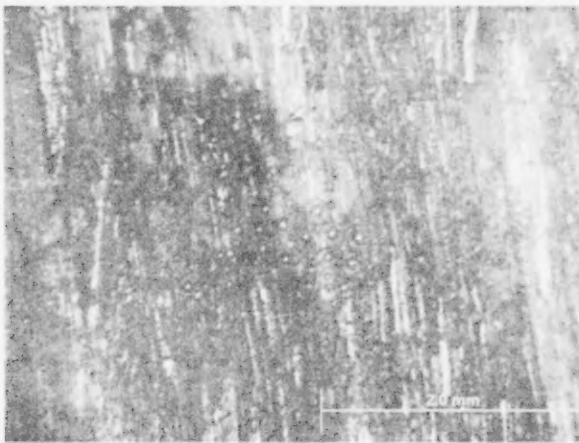


Figure 25. Distribution of industrial glass microspheres sprayed at high loading onto the OSB surface and showing clumps of microspheres and bare patches.

Table 19. Droplet contact angles and times for droplets to recede to a contact angle of 50° (or 100° where indicated) for OSB treated with microsphere types and loadings

	<i>C_i(deg)</i>	Time to 50° (sec)
OSB surface	108	1000
UW5F 1%	110	750
Industrial MS low	108	312
Industrial MS med	101	424
Industrial MS high	108	891
38-45 low	104	364
38-45 med	98	1072
38-45 high	100	1492
63-75 low	108	180
63-75 med	113	755
63-75 high	114	1819
90-106 low	95	429
90-106 med	114	466
90-106 high	102	532
180-212 low		No microspheres on surface
180-212 med		
180-212 high		

Each mean is the average of 10 contact angle runs

Despite having relatively little effect on initial droplet contact angle, adding a higher loading of microspheres tended to increase the time in which a droplet stayed on the surface (Table 19). The greatest effect on droplet-residence time came with the addition of 63–75- μm spheres in high-loading solution (0.2 g in 20 mL). In contrast, the addition of low or medium doses of microspheres to the surface resulted in a shorter droplet-residence time, of between about 200 s and 500 s. For larger sizes (larger than 90 μm), microsphere loading had little effect and, when observed under the light microscope, microsphere distribution was very sparse even at higher loadings.

3.4.1.4 Droplet behaviour on the surface with a continuous layer of microspheres adhered to melamine

The results for droplet behaviour on samples onto which a layer of microspheres had been deposited were surprising. Instead of the droplet sitting on the surface, it was sucked down and disappeared into the surface within one second. This occurred for all glass-microsphere types and sizes tested. The most likely explanation for this is that the microspheres form a layer of hydrophilic material (glass) and a network of tiny capillaries that draw water through them under capillary tension. It is possible to see how this would occur, especially in the larger microspheres, by looking at Figure 23 (e and f), where large interstitial gaps between the adjacent microspheres are visible. From this finding, it is apparent that if spherical particulates such as glass microspheres are used as a surface-topography modifier and void-filling material, they need to be coated with a strongly hydrophobic material or embedded in an impervious matrix or cement that fills the interstitial spaces and blocks the paths for water.

The application of a strongly hydrophobic substance to the microspheres largely counteracts these capillary tension forces. A droplet of water sat on the top of the layer of microspheres after they are sprayed with a hydrophobic siloxane water-repellent substance. Sample contact angles for the water-repellent-sprayed microsphere surfaces were greater than 100°, and usually 110°–120°.

3.4.1.5 Thickness swell of oriented strand board treated with glass microspheres

The results indicate that adding glass microspheres to sample surfaces as a part of the emulsion treatment spray does not further restrict OSB water absorption and thickness swell beyond that provided by the low-concentration emulsion wax on its own (Tables 20 and 21). Contrary to expectations, adding the glass microspheres to melamine also had no additional beneficial effect on thickness swell beyond what could be achieved by using wax emulsion alone. The use of MF resin to bind the microspheres to the surface was complicated by the inability to obtain an even and consistent film onto which to deposit the microspheres even when the board surface was hot. As well, the resin would gel quickly during application to a heated board surface. Surprisingly, the application of melamine to the surface did not restrict OSB thickness swell, possibly because of the inability to coat the surface evenly and the deterioration of the melamine by water. The reaction of the melamine with water gave the surface a white appearance after exposure and drying.

Table 20. Average thickness swell values for OSB treated with wax emulsion, wax emulsion + glass microspheres, and melamine + glass microspheres (Replicate 1).

	2 h TS (%)	6 h TS (%)	24 h TS (%)	48 h TS (%)
controls	3.05	5.49	12.20	20.25
1% UW5F	1.30	3.15	8.18	16.64
1% UW5F + glass MS	2.67	5.05	11.29	18.50
Melamine + glass MS	2.19	5.79	10.91	18.94

Each mean is the average of 6 samples; 12 for controls

Table 21. Average water absorption values for OSB treated with wax emulsion, wax emulsion + glass microspheres, and melamine + glass microspheres (Replicate 1).

	2 h WA (%)	6 h WA (%)	24 h WA (%)	48 h WA (%)
controls	4.93	7.56	17.85	33.11
1% UW5F	3.47	5.15	13.10	29.42
1% UW5F + glass MS	3.62	6.21	13.54	28.86
Melamine + glass MS	4.97	12.55	15.01	29.43

Each mean is the average of 6 samples; 12 for controls

Droplet contact angle measurements show that applying low concentrations of glass microspheres decreased the residence time for water droplets on the treated surface of OSB to below that of untreated OSB, indicating that a micro-channelling effect had occurred that enhanced the spread of water droplets. This effect was most pronounced when a high-concentration microsphere solution was added to the surface without any co-occurring hydrophobic substance such as wax. In the micro-channelling effect, increasing surface roughness could help make surfaces more wettable if the chemistry of the surface itself is not strongly hydrophobic and how the roughness breaks up the surface tension of the water droplets, causing them to flow outwards along channels. The same effect was ascribed by Kohonen (2006) to the warty layer lining the insides of cell lumens in the conductive xylem of certain trees and shrubs adapted to of higher moisture-stress growing conditions. There, the lumen nodulation decreases contact angle with water menisci, producing greater capillary tension force per lumen diameter to more effectively draw water up through the conductive cells.

Increasing the concentration of small (smaller than 80–90 µm) glass microspheres on the OSB surface resulted in a noticeable increase in droplet-residence time, in some cases higher than that of control or emulsion wax-treated surfaces. The phenomenon of reducing water droplet spreading by increasing surface roughness when the rough surface is chemically hydrophobic is known as the *lotus effect* (described in Section 2.4.1; Baker 1982; Barthlott and Neinhuis 1997; Parkin and Palgrave 2005). The effect appears to have been weakly expressed here, because the microspheres were associated with a very small amount of wax from the emulsion solution they were applied with. The reversal-surface wettability was more apparent in the case of the continuous layer of microspheres that were then sprayed with strongly hydrophobic cotton fabric protector. Cassie and Baxter (1944) showed how surface chemistry and its free energy dictates the effect of surface roughening; i.e., if the surface is already wettable, micro roughening can make droplets spread more easily, whereas if the surface is strongly hydrophobic, micro roughening can make it more hydrophobic.

This did not, however, translate into decreased water uptake and thickness swell when the treated samples were soaked. This is likely because the microspheres tended to wash off the surface during soaking and handling. Their removal from the surface also likely removed some of the applied emulsion wax, which may help explain the small increase in water uptake and thickness swell observed for the glass microsphere-treated boards.

Despite the wax–microsphere treatments for OSB not being effective at reducing water uptake and thickness swell, much was learned about the practicalities of adding glass microspheres to water-based carriers and applying them by sprayer. The rapid accumulation of spheres at the top or bottom (in the case of the large ones) of the carrier solutions required constant agitation of the container. This meant that such a treatment system would require a carefully balanced suspension of the particulates via the use of emulsifiers. The emulsion-wax solution was unable to form a continuous distribution over the surface without coalescing into droplets unless the board surface was very hot and the emulsion wax contained sufficient surfactant to break up the surface tension of the water. It was shown that as the dosage of emulsion wax increases, its efficacy at restricting

water uptake and thickness swell is reduced due to the increased amounts of hydrophilic surfactant added to the surface. As the applied solution dried, distribution of spheres on the board surface was patchy and discontinuous: spheres accumulated in some areas and not in others. As microsphere size increased, the ability to eject them onto the surface through a spray nozzle decreased: in the case of sizes approaching 100 μm , few or no microspheres were present on the surface.

3.4.2 Plastic Microspheres as Surface-Texturing and Void-Blocking Agents

3.4.2.1 Surfaces treated with expanding/nonexpanding microspheres

This phase of the work further explored the use of micro-particulates to modify surface roughness and hydrophobicity, with the main objective of using expanding plastic microspheres that could be transported down into surface crevices and then heat expanded to fill and block the cavities. Dispersing the microspheres in ethanol proved to be a more effective method of treating OSB surfaces with microspheres. Because microspheres were evenly dispersed in the alcohol, the solution spread easily over a cold board surface and into crevices without need for a hydrophilic surfactant, and flashed off quickly without causing any significant preliminary swelling of surface strands. The water-only medium for the microspheres beaded up on the surface, even when the board surface was preheated. The water-plus-commercial-wax-emulsion medium allowed the treatment solution to spread over the heated surface and into crevices due to the presence of surfactant keeping the wax emulsified. Another drawback of having to apply the expanding microspheres to a hot board surface was the pre-expansion of the microspheres that occurred before they penetrated into surface crevices. For these reasons, application in ethanol was the preferred method for applying expanding microspheres.

A distinguishing feature of the surface treatment with expanding microspheres not embedded in a polymer matrix is that heat expansion of the microspheres resulted in a large dusty surface florescence of expanded microspheres on boards (Figure 26). This problem was largely overcome by adding the expanding microspheres in a carrier of low-solids content PF resin or in hard-setting linseed oil. In the case of the PF carrier, the microspheres expanded but held together to form a kind of uneven foam over the surface (Figure 27). The foam was relatively easily dislodged from the surface by rubbing.

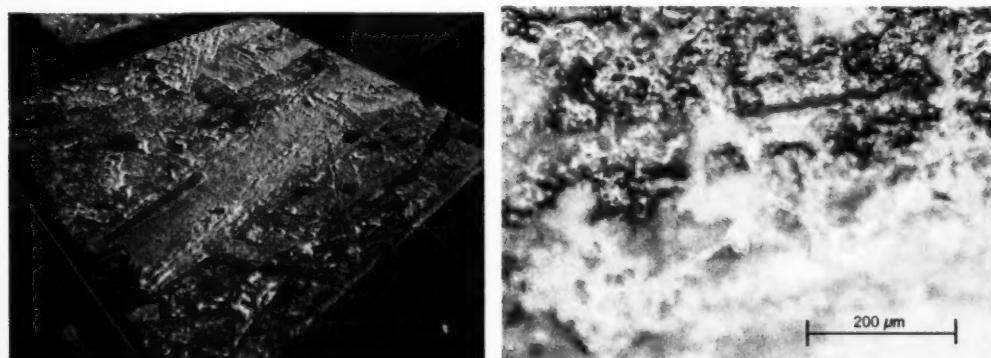


Figure 26. (a) Expanded microspheres (20 μm unexpanded) on a treated and dried OSB surface, and (b) magnified 20X.

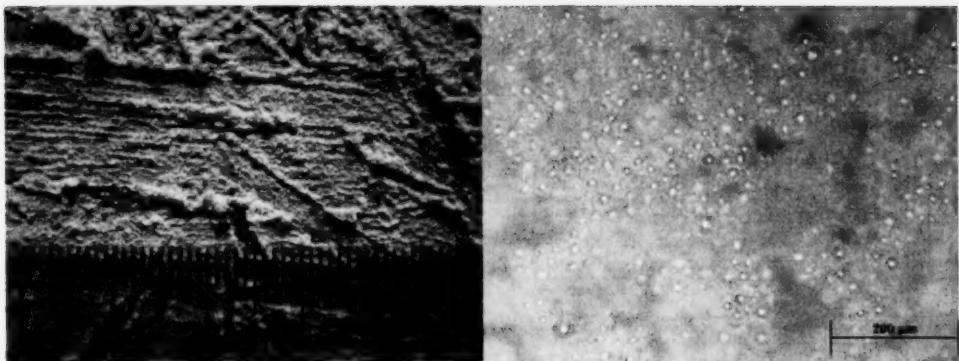


Figure 27. (a) Appearance of OSB surface after heat treatment with expandable microspheres in dilute PF resin, and (b) expanded surface foam magnified 8x under a light microscope.

The diluted PF resin was also used to fix common grades of nonexpanding microspheres, i.e., glass and phenolic microballoons, to the surface and into voids (Figure 28).

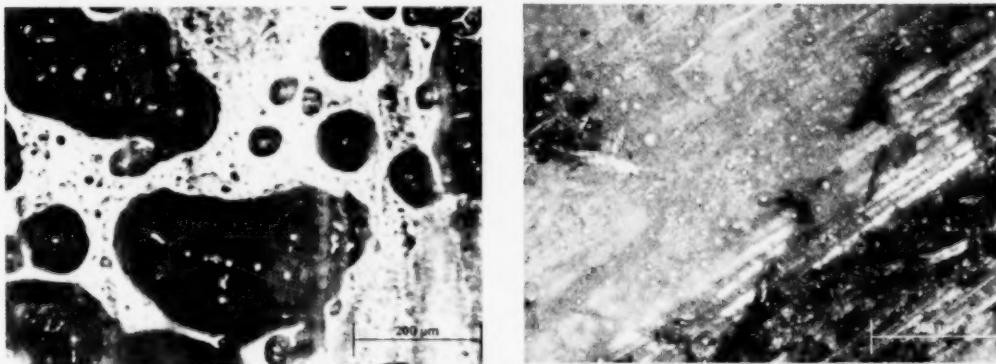


Figure 28. Appearance of glass microspheres (a) on the surface and (b) lining a crevice where two strands overlap.

3.4.2.2 Surfaces treated with linseed oil and expanding/nonexpanding microspheres

Dispersing the expanding plastic microspheres in linseed oil was difficult as there was no water in the system to break down the caking agent that keeps the microspheres from separating and dispersing into the air. Dispersing as little as 0.03 g/mL of unexpanded plastic microspheres into linseed oil increased the viscosity of the coating, enabling it to be applied more thickly than linseed oil only.

Another type of coating could be produced by heating the expandable microspheres in an oil or oil-wax mixture at 80° C for a few minutes to expand them and then allowing the mixture to cool. This process expanded the volume of the oil-based coating to about twice its original volume and resulted in a latex-like paste. This was applied easily to board surfaces by brush or roller coater and was of sufficient bulk to fill surface crevices. However, the expanded microspheres were too large to fill very small pores in the board and then be expanded to plug them.

The linseed oil-expandable microsphere coatings covered the surfaces of strands fairly well and expanded to fill surface cracks and crevices fairly well (Figure 29).

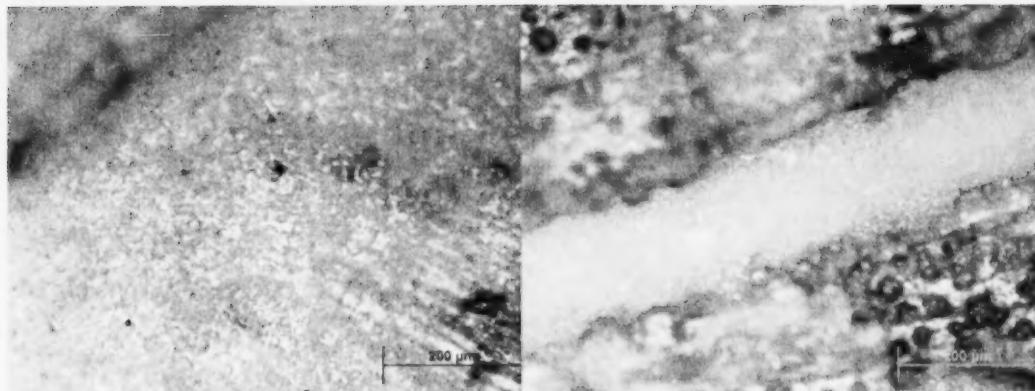


Figure 29. Linseed oil and expanding microspheres coatings (a) on surface strands, and (b) in crevices in the surface of the board

Nonexpanding industrial glass and phenolic microspheres were also applied in linseed oil. The presence of microspheres helped retain more linseed oil on the surface, because the oil tended to stick to the microspheres and accumulate around the base of the microspheres (Figure 30). It was first thought that this may help reduce thickness swell and water absorption.

There are two additional things to note in Figure 30: Firstly, sphere sizes range from a few micrometers to more than 50 μm in diameter, and secondly, the microspheres tended to form aggregates, and therefore distribute unevenly across the surface.

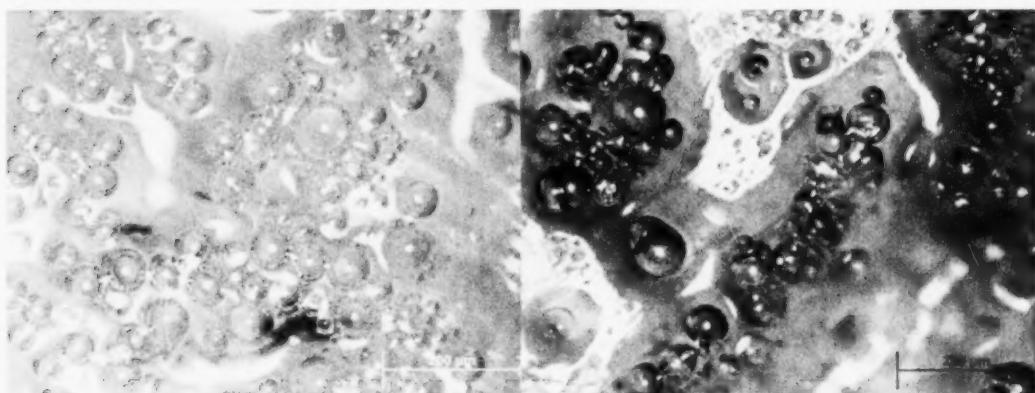


Figure 30. (a) Glass and (b) phenolic microspheres in linseed oil on the surface of OSB at 8X magnification

3.4.2.3 Contact angle measurements

Applying a relatively small quantity (0.03 g/mL) of fixed-size microspheres (phenolic or glass) to the surface reduced the contact angle and particularly the droplet-residence time to about one minute or less (Table 22). Droplets spread quickly, most likely because of micro-channeling. In accordance with the results for the glass microspheres covered in Section 3.4, increasing the loading of microspheres to 0.1 g/mL increased the droplet contact angle to above that of control boards and retained droplets on the surface for longer. Applying PF resin or microspheres made from PF resin caused a reduction in contact angle and droplet-residence time compared to the angle and time for the control board. These results improved somewhat by adding glass microspheres; glass and phenolic microspheres may vary in their attraction to water, with the

phenolic microspheres possibly being made from a more hydrophilic material than the glass microspheres are.

A particularly striking finding was that a layer of expanded plastic microspheres on the surface of boards had a strong effect on the initial contact angle, keeping water droplets almost spherical on the surface for a long time. The expanding plastic microspheres expanded and joined together to form a loose web of very hydrophobic material, particularly in the case of the 20- μm and 40- μm spheres. The effect was less pronounced with the 80- μm spheres. The 80- μm spheres are more heat resistant and did not fuse together into a web as easily as the smaller sizes did: this may account for the reduced contact angle and droplet-residence time on the 80- μm microsphere-treated samples.

Applying the expanding microspheres in a thermosetting (PF, in this case) resin eliminated the surface-dust problem. However, it also caused water droplets to spread and penetrate the foam within seconds. Adding microspheres to linseed oil had relatively little effect on droplet behaviour, although adding glass or phenolic microspheres both slightly increased droplet-residence time by several minutes. This may be related to the ability of the microspheres to retain more of the oil barrier on top of the strands instead of penetrating through the surfaces of strands as happens when applying only linseed oil.

Table 22. Average droplet contact angles (C_i) and time taken for a droplet to recede to a contact angle of 50° for OSB surfaces treated with microspheres alone or in a PF or linseed oil medium.

	Loading	Contact angle (C_i)	Time to 50° (mins)
Control	-	107.0	16
Microspheres on their own			
Ind. glass microspheres	0.03 g/mL	90.0	1.0
Ind. glass microspheres	0.1 g/mL	124.9	38.6
Phenolic microspheres	0.03 g/mL	90.4	0.8
Expancel 20- μm microspheres	0.03 g/mL	129.4	87
Expancel 40- μm microspheres	0.03 g/mL	118.1	78
Expancel 80- μm microspheres	0.03 g/mL	106.5	40
In PF resin			
PF only	-	99.8	9.0
Ind. glass microspheres	0.03 g/mL	110.1	22.9
Phenolic microspheres	0.03 g/mL	93.2	2.9
Expancel microspheres	0.03 g/mL	99.7	0.2
In linseed oil			
Linseed oil only	-	103.7	50
Ind. glass microspheres	0.03 g/mL	104.3	63.6
Phenolic microspheres	0.03 g/mL	111.2	61.6
Expancel microspheres	0.03 g/mL	93.2	43

Each mean is the average of 10 contact angle measurements.

3.4.2.4 Thickness swell and water absorption

The only type of microsphere capable of effectively reducing the short-term OSB thickness swell was the expandable type (Tables 23 and 24; Figure 31). After 2 h or 24 h of continuous exposure to water, there were no statistically significant (at $p \leq 0.05$) differences between controls and the fixed-size glass or phenolic microspheres used either on their own, in PF resin, or in linseed oil. In contrast, the expanding microspheres on their own reduced 2-h thickness swell to less than half that of untreated board.

Table 23. The average thickness swell for OSB treated with fixed-size and expanding microspheres alone, with linseed oil, or with PF resin.

	2h	6h	24h	48h
Control	2.43	4.56	9.72	14.64
Glass microspheres	2.93	4.95	10.81	16.86
Phenolic microspheres	2.95	5.66	12.79	19.24
Expancel 20- μ m microspheres	1.12	2.83	6.82	10.98
Expancel 40- μ m microspheres	1.50	3.43	8.71	13.21
Expancel 80- μ m microspheres	1.91	3.66	12.10	14.18
Linseed oil	1.82	3.97	10.44	16.23
Linseed oil + glass microspheres	2.86	6.72	14.11	19.64
Linseed oil + phenolic microspheres	2.69	6.63	16.47	23.36
Linseed oil + Expancel	0.33	2.04	7.27	12.48
20% solids PF resin	3.33	5.85	12.53	17.30
PF + glass MS	3.42	5.85	11.26	15.50
PF + phenolic microspheres	3.08	5.25	10.48	15.52
PF + Expancel	1.38	3.51	7.44	12.17

Table 24. The average water absorption for OSB treated with fixed size and expanding microspheres alone, with linseed oil, or with PF resin.

	2h	6h	24h	48h
Control	3.31	5.62	11.83	17.71
Glass microspheres	3.43	5.93	12.92	22.27
Phenolic microspheres	4.35	7.33	15.78	25.02
Expancel 20 μ m	4.16	6.82	13.80	21.10
Expancel 40 μ m	4.54	7.83	17.01	25.61
Expancel 80 μ m	4.82	8.14	15.63	24.42
Linseed oil	3.01	6.30	15.52	25.25
Linseed oil + glass microspheres	5.00	9.10	18.99	28.34
Linseed oil + phenolic microspheres	5.32	9.28	23.26	34.20
Linseed oil + Expancel	3.29	5.55	12.76	20.69
20% solids PF resin	5.04	7.86	15.12	23.31
PF + glass MS microspheres	3.74	6.35	12.85	19.72
PF + phenolic microspheres	4.00	6.54	13.31	20.55
PF + Expancel	5.13	7.94	13.85	21.86

After 24 h of continuous exposure to water, the difference in thickness swell between boards treated with the expanding microspheres and the controls was reduced (Figure 37b). Despite the effective reduction in thickness swell with the expandable microspheres, there were no significant differences in water absorption between any treatment or control. From Figure 37, water absorption for boards treated with the expandable microspheres was much higher relative to thickness swell than for the other treatments. This suggests that although expanded-microsphere layer was highly water absorbent, the water was largely prevented from being absorbed into the composite itself, possibly because the spheres plugged pores and crevices. It was originally thought that the smallest of the phenolic and glass microspheres (Figure 30) might be better able to penetrate smaller pores in the surface; however, there was little difference between the thickness swell behaviour of the OSB treated with these fixed-size microspheres and the controls.

(Figure 31). There was a slight, but not statistically significant, increase in thickness swell and water absorption with the addition of glass or phenolic microspheres to the surface compared to those of the controls.

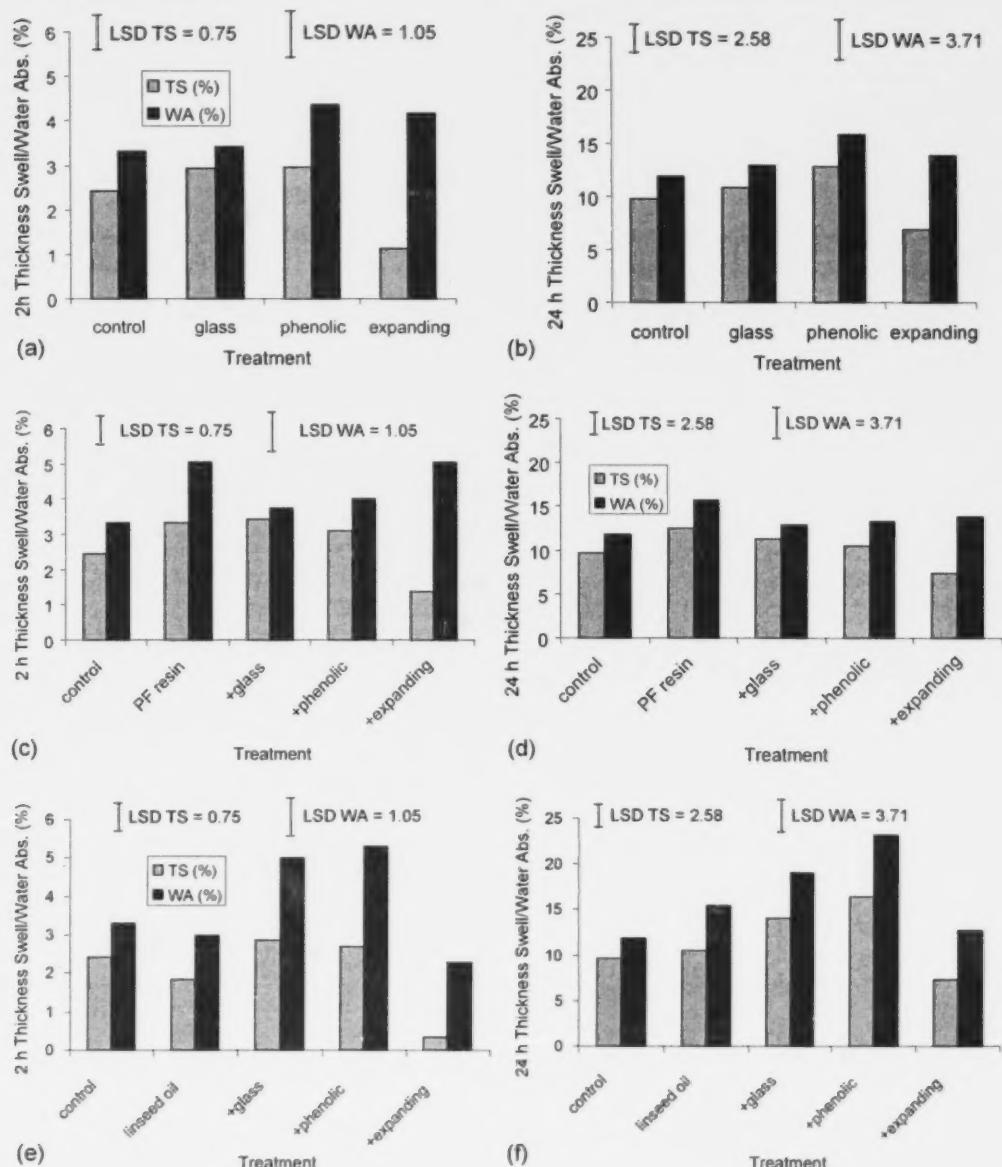


Figure 31. 2-h (a) and 24-h (b) thickness swell and water absorption for OSB treated with microspheres on their own; 2-h (c) and 24-h (d) thickness swell/water absorption for OSB treated with microspheres in PF resin, and; 2-h (e) and 24-h (f) thickness swell/water absorption for OSB treated with microspheres in linseed oil. Least significant difference bars are shown to enable statistical comparison of means. Each mean is the average of five replicates.

The water-retarding effect of adding expanding microspheres on their own was variable because the layer of microspheres was more easily washed or rubbed off than in other treatments. The problem of dust and the expanded microspheres washing off during soaking—thereby reducing their full potential effect at blocking out water—was addressed by applying them in the unexpanded state in a dilute solution of PF resin and curing the resin for approximately 15 min. A layer of stiff foam over the surface resulted. The problem of dislodging the coating from the surface during exposure to water was reduced (Figure 32). The PF-bonded Expance foam softened with time during exposure to water and was easily dislodged by rubbing.



Figure 32. Expance-treated specimens after 2 h soaking in water. The left piece was treated with Expance in PF resin; the right piece was treated with Expance alone in ethanol. The light-coloured zones are where the Expance stuck to the board.

The fixed-size microspheres were added in a suspension in PF resin diluted to 20% solids content. The resin was heat set, and the microspheres adhered to the surface without rubbing or washing off in water during soaking. Boards treated with cured PF resin with or without fixed-size glass or phenolic microspheres experienced increased water absorption and thickness swell compared to untreated boards. The presence of the cured PF on the surface appears to have increased the boards' susceptibility to water absorption and thickness swell. The dilute-resin treatment may have chemically interacted with and disrupted the OSB surface layer that provides some degree of short-term resistance to water absorption and thickness swell. In addition, PF resin reacts with water and the cross-linked structure can swell (Sinha 2004), a phenomenon that may have been exacerbated by the dilution of the adhesive with water prior to application. The addition of glass or phenolic microspheres to the PF resin reduced the thickness swell of boards treated with PF resin alone: this may because the same weight of mixed coating applied to cover the surface resulted in a reduced quantity of PF resin being applied.

The beneficial effect of expanding microspheres applied alone and left undisturbed on the surface of swellometer specimens can be seen in Figure 33. For soaking periods of up to about 75 hours, the undisturbed Expance-treated surfaces restricted surface swelling to 50% or less. As can also be seen Figure 41, the sizes of expanding microspheres that most effectively reduced surface swelling were the 20- μ m and 40- μ m grades: in some cases thickness swell was reduced to 50% or less of that of controls. The 24-h and 48-h thickness swell of OSB treated with the 80- μ m grade spheres were either the same or higher than that of the control boards (Table 23; Figure 34). The

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larger-sized expanding microspheres were less effective at restricting OSB surface swelling. This supports the concept that the smaller the particles before expansion, the smaller the crevices they can penetrate and plug. It was also observed that the largest-sized microspheres did not fuse together with heating into foam as easily and tended to remain as discrete entities: this may have resulted in water wicking into the surface.

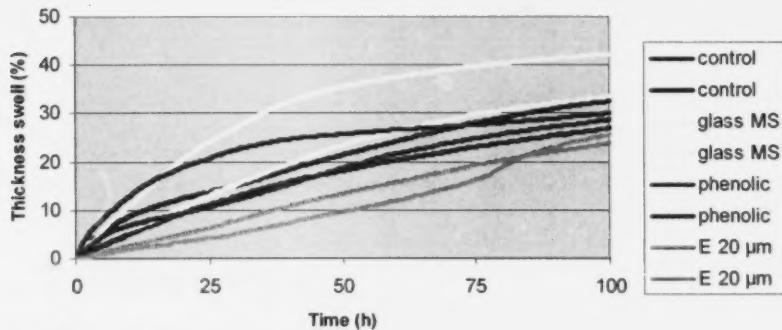


Figure 33. Continuous thickness swell of OSB surfaces treated with different kinds of microspheres (glass, phenolic, or expanding plastic).

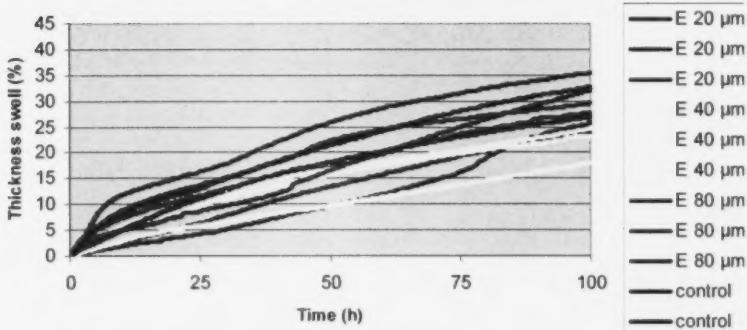


Figure 34. Thickness swell of OSB treated with expanding-plastic microspheres of different sizes.

All of the surface-texturing treatments other than the expanding microspheres had little or no effect on baseline resistance to thickness swell of untreated boards (Figure 35). The ability of the expanding microspheres to restrict thickness swell was similar whether they were bonded with PF resin or not.

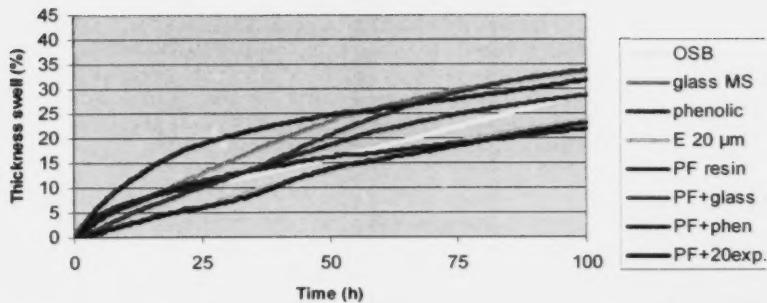


Figure 35. The effect of adding expanding/nonexpanding microspheres to the surface of OSB.

3.4.2.5 Linseed oil coatings containing microspheres

The best of all of the different treatments was the linseed oil plus expanding microspheres mixture (Figure 36). This treatment imparted excellent resistance to short-term (2-h) exposure to water, reducing the average 2-h thickness swell to less than 0.5% compared to almost 2.5% for controls. The material in the expanding plastic microspheres is strongly hydrophobic, and likely contributed to creating a more hydrophobic coating material than linseed oil alone. Because of linseed oil's propensity to be break down with water, the difference between linseed oil-treated boards and controls was reduced after 24 h or more of exposure to water, such that there was little difference between the two. In contrast, after 24 h of exposure, thickness swelling of the linseed oil-Expancel-treated boards was still less than that of untreated controls. Even over longer, continuous exposure to water (up to 100 h), thickness swelling of some linseed oil-Expancel-treated specimens remained almost 50% less than that of controls (Figure 36), but the effect was variable. A factor that may have contributed to the improved performance of the linseed oil-Expancel mix is that the liquid became thicker and less prone to seeping into the board (Figure 29): this may have provided a thicker barrier better able to reduce water absorption.

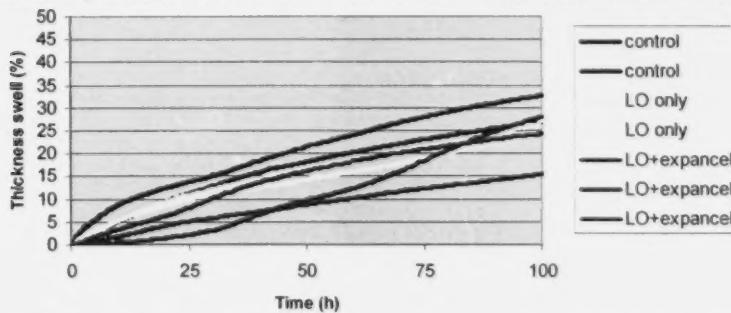


Figure 36. The effect on surface swelling of using a linseed oil-Expancel mix compared to using linseed oil alone.

In contrast to the findings for the linseed oil-Expancel mix, applying a mix of linseed oil-glass/phenolic microspheres to the board surface resulted in greater water absorption and thickness swell compared to linseed oil alone (Figure 31 e and f). From the appearance of the treated boards (Figure 30), it had been surmised that the microspheres may retain more of the linseed oil on top of the board and perhaps increase resistance to moisture absorption and thickness swell. However, the opposite occurred, whereby thickness swell and particularly water

absorption were markedly higher than that of boards treated with linseed oil alone. One possible explanation for this may be that, as the same volume of coating was applied, the presence of the particulates not only reduced the total amount of linseed oil being applied to the surface but broke up the continuity of the cross-linked linseed oil coating, which provides temporary physical barrier to moisture ingress.

3.5 Experiment 5: Roller-Coated Oriented Strand Board

3.5.1 Coating-spread rates

Passing the boards under the roller coater once or twice limited the amount of coating placed on the boards compared to that which resulted by brushing it on. By far, the greatest spread rate was achieved by brushing the Thompson's water repellent onto the boards (0.1235 g/cm²; Table 27). The heavier the coating, the greater the weight placed on the board, which was the case for the UV-cured oil containing photo-reactive polymers.

Table 25. Spread rates and number of coats for roller-coated OSB, by coating.

Treatment	Spread rate (g/cm ²)
1 coat Thompson's water repellent	0.00156
2 coats Thompson's water repellent	0.00256
Thompson's water repellent brushed on	0.1235
1 coat Expancel + PF resin (20% solids)	0.00203
2 coats Expancel + PF resin (20% solids)	0.00256
1 coat Expancel + linseed oil	0.00291
2 coats Expancel + linseed oil	0.00452
1 coat UV-cured oil	0.00399
2 coats UV-cured oil	0.00704

3.5.2 Surface observations

The gap between rollers and the pressure of the roller-coat applicator were adjusted in order to get as even a coat finish as possible over the board surface and enable some of the coating to soak into surface crevices. Even with adjustment, the first pass often resulted in a thin and, to the eye, uneven layer, particularly in the case of the thinner coatings—PF resin/water plus expanding microspheres and the Thompson's water repellent. After two passes, coat uniformity improved greatly and more of the low-viscosity liquid was observed in the surface crevices. The higher-viscosity oil-based finishes, i.e., the UV-cured finish and the linseed oil–microsphere mix, resulted in more of the finish on the surface strands but less infiltration into surface crevices.

In the case of the Expancel–PF resin mix, one pass through the roller coater was insufficient to create a continuous film of coating on the boards. After heat expanding the microspheres, it became apparent that there were few, if any, expanded spheres on the surface; instead, they accumulated in some of the surface crevices. Two passes through the roller coater resulted in a somewhat better covering of expanding microspheres across the surface and more in the surface crevices. Some tests were done with three coats: these resulted in more Expancel on the tops of the surface strands (Figures 38 and 39).

Results for the thickness swell and water absorption of roller-coated boards have yet to be completed.



Figure 37. The outcome of roller coating boards with one pass, two passes, and three passes with a mixture of expanding microspheres and PF resin at 20% solids content.



Figure 38. Close-up views of the top surfaces of boards shown in Figure 46 after (a) one coat, (b) two coats, and (c) three coats.

3.5.3 Ultraviolet-cured coatings

The average spread rate (amount of coating on the surface per unit area) for the ACI UVO 5062G5-25 (see Section 2.4.3.1 for treatment coatings list) was 0.047 g/cm^2 and for the Akzo-Nobel Rel-Tuff UV topcoat 0.013 g/cm^2 . Average thickness swell and water absorption over 2 h, 6 h, 24 h and 48 h for OSB treated with two different brands of UV-cured oils are given in Tables 25 and 26. The first product, ACI UVO 5062G5-25, reduced water absorption and thickness swell to 30%–50% less than controls, with the coating being more effective at lower durations of exposure to water (2 h and 6 h). The second product, Akzo-Nobel Rel-Tuff UV high-gloss topcoat, had the opposite effect: it exacerbated water absorption and thickness swell to more than that of untreated OSB (the control). In the topcoat-coated specimens, there was considerable roughening of the surface strands and a uneven surface topography after soaking samples in water for 24 h or more (Figure 37a), whereas after a long period of soaking, the UVO 5062G5-25 tended to undergo localised cracking and peeling where water had got in and strands underneath had swelled (Figure 37b).

Table 26. Average thickness swell of OSB treated with two UV-cured oils.

	2 h	6 h	24 h	48 h
Control	2.43	4.56	9.72	14.64
ACI UVO 5062G5-25	1.55	2.87	6.73	10.29
Akzo-Nobel Rel-Tuff UV topcoat.	2.18	5.70	14.83	20.64

Table 27. Average water absorption of OSB treated with two UV-cured oils.

	2 h	6 h	24 h	48 h
Control	3.31	5.62	11.83	17.71
ACI UVO 5062G5-25	1.44	2.65	5.69	9.89
Akzo-Nobel Rel-Tuff UV topcoat.	2.91	6.30	15.40	23.89

Each mean is the average of four specimens.

There are two possible reasons for the differences in performance of the two UV-cured coatings. Firstly, upon application, the UVO 5062G5-25 was more viscous than the topcoat product and produced a thicker coat over the surface. The topcoat product was less viscous and resulted in a lower spread rate and a thinner coat. This is because it is designed to be applied as a very thin topcoat to a surface that has already had pores filled and an undercoat applied, and likely performed poorly in this case because it was applied directly to the pitted OSB surface. It was applied this way in order to compare it with the other treatments applied directly to the board surface as a one-step application. After curing the topcoat product, more of a volatile odour remained, and it is likely that, where the coating seeped into the surface crevices of the board, the coating did not cure properly and allowed water to penetrate. Compared to untreated boards and some of the custom coatings developed in this project, such as the linseed oil-wax and linseed oil-Expancel mixes, the UV-cured topcoat resulted in greater thickness swell and water absorption. The coating may have chemically interfered with the heat-sealed surface of the OSB: this may be why the product is specified by the manufacturer (Akzo-Nobel) to be used as a topcoat over one or more layers of filler and an undercoat on wood substrates.

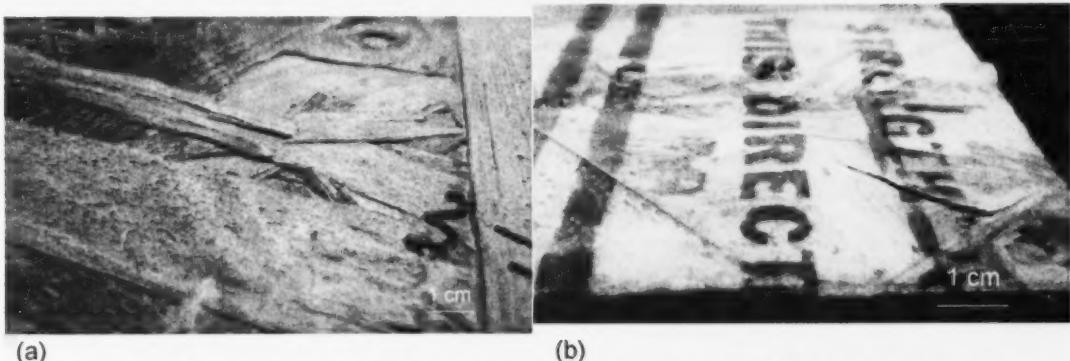


Figure 39. Surface appearance of (a) Rel-Tuff-coated specimen and (b) UVO 5062G5-25-coated specimen after 48 h of continuous exposure to water.

No matter how well sealed, wood shrinks and swells over time with exposure to liquid or air-borne moisture (Feist 1997). Rigid-film coatings (such as oil-based paints, UV-cured oils or cured-polymer layers, in this instance) come under considerable tension stress as the wood swells beneath it, causing delamination at the paint-wood interface and micro-fracturing or even visible cracking of the paint film itself (Imamura 1973a, b; Figure 37). While rigid oil based paints provide the best barrier protection against liquid water and water vapour, a range of flexible latex- and elastomer-based paints that accommodate the movement of the wood substrate have been developed to counter brittleness and cracking of paint films. However, these products form

porous coats and allow moisture through to the wood more easily. Additives, such as expanding plastic microspheres, that fuse with the polymer matrix and are expandable and compressible help dissipate the internal stresses applied to the matrix (Wood 2008). The stress is mainly from thermal expansion and contraction of the matrix, but such stresses on a paint-polymer coating could also come from swelling of the wood. The addition of flexible plastic microspheres such as Expanceal may make brittle barrier coatings such as oil-based air and/or UV-cured paints more flexible yet still hydrophobic. This avenue of investigation deserves further attention.

4 Conclusions

4.1 Experiments 1 and 2: Wax-Emulsion Types and Concentrations

In the *study* on the effects of emulsion-wax types and concentrations, it was hypothesized that applying commercial water-repellent wax emulsions to OSB surfaces would provide a degree of protection from moisture absorption and thickness swelling, and that concentrations of wax higher than the 1% normally used during blending might further improve the moisture resistance of boards. The improvement in OSB moisture resistance was not as high as initially expected and provided only very short-term resistance to water uptake and swelling. The main findings from the two studies are as follows:

1. Cascowax formulation was difficult to apply evenly to board surfaces due to its propensity to bead on the board surface, even after heating. This was thought to be the main factor reducing the efficacy of this emulsion.
2. The application of Cascowax at 2.5% resulted in the lowest OSB water uptake and thickness swelling after shorter periods of soaking (2 h, 6 h and 24 h), whereas the UW5F formulation at 1% resulted in the lowest water uptake and thickness swelling after longer exposure to water (48 h of soaking). This latter formulation may have worked better because it was able to spread and fill the deeper depressions on the board surface.
3. Using emulsion waxes at higher concentrations (5%) negatively effected OSB resistance to water, particularly in the case of UW5F. This was thought to be a side effect of increasing the quantity of hydrophilic surfactant applied to the surface, this being why UW5F was less prone to beading. The hydrophilic surface created from adding greater concentrations of UW5F was particularly evident in contact angle measurements, whereby droplets spread over and soaked into the surface very rapidly.
4. Emulsion-wax application had little effect on the water droplet contact angle compared to those of the controls, but increased the time that droplets remained on the surface.
5. The relationship between water absorption and thickness swelling of samples was highest after 24 h of soaking and lowest after 2 h of soaking, supporting the idea that water likely fills void spaces first before penetrating the compressed-wood cell walls and directly causing thickness swelling.
6. The effect of wax application was relatively short lived, possibly because of a combination of the well-known phenomenon of preferential wetting, whereby wax molecules are displaced from the wood substrate by water molecules with greater bond energy, and the surface of OSB being more hydrophobic and more highly compressed compared to solid wood, which would further reduce the ability of the emulsion to spread and penetrate the surface strands.
7. Boards that showed greater water absorption and thickness swelling (such as the controls or those treated with UW5F at 5%) retained their higher water content and degree of swelling over the course of conditioning drying. The type of wax or its concentration had no effect on the rate at which samples were able to lose water and reduce in thickness. Average non-recoverable thickness swell was 13.25%.

8. Contrary to expectations, all of the trial custom-made wax emulsions (i.e., the non-commercial treatments containing industrial slack wax, soy wax, beeswax, and carnauba wax) exacerbated water absorption and thickness swelling of OSB sprayed with the wax emulsion. This observation was associated with lower water droplet contact angle and greatly reduced droplet-residence time on the surface compared to those of the controls or of specimens treated with the commercial wax emulsions. In contrast, proprietary wax emulsion formulations manufactured for use in combination with wood-preservative chemicals or resins to give treated wood or composite boards greater dimensional stability increased the dimensional stability of OSB compared with a water spray containing no wax. Two factors that may have adversely affected the performance of the trial wax emulsions: the pre-swelling of surface strands in response to spraying the hot surface with a water-based emulsion, and the type and concentration of surfactant designed to keep the wax particles in a stable emulsion being different from those of the commercial emulsions. Generally, the best of the trial waxes was the carnauba wax, which is also the hardest of the four tested.

4.2 Experiment 3:

4.2.1 Linseed Oil-based Coatings

Due to the problems associated with applying water and hydrophilic surfactants to OSB surfaces, the next phase of the project concentrated on application of non-aqueous coatings to the boards in the hope of further enhancing resistance to moisture absorption and thickness swell. The application of linseed oil-based coatings containing hydrophobic waxes was investigated with a view to overcoming problems associated with having surfactant in the applied water-repellent treatment and having to apply water to the surface, which can result in pre-swelling and roughening. The wax could be readily dissolved into the linseed oil through melting at a low temperature (40°–70° C) without need for emulsification. One coat of a range of oil-wax hybrid coatings were compared with one coat of a variety of commercial coating products sold for use on wood. The conclusions from this phase of the project are summarised as follows.

1. One coat each of commercial wood and floor lacquers and finishes, especially the water-based acrylics and urethanes, mostly exacerbated the swelling response of OSB compared to the response of untreated boards. This may not be unexpected, as manufacturers recommend these projects be applied in multiple coats in order to be effective. Applying urethane wood finish in the recommended four coats greatly improved the performance of the treatment; however, in terms of industrial OSB coating, the drawbacks are the amount of finish required and the long drying time between coats.
2. The combination of linseed oil and a more hydrophobic wax (such as beeswax or paraffin wax) provided better protection from water uptake and swelling, especially in the short term, than did no treatment, straight linseed oil, a commercial emulsion wax, and most of the commercial reference coatings. Linseed oil-wax mixtures reduced the short-term (up to 24 h) thickness swell to half or less of that of untreated control boards or those coated with linseed oil only. The coating effect is relatively short lived, because the hardened linseed oil starts to break down after more than a day or so of continuous exposure to water.
3. Obtaining an even, hardened skin of cross-linked oil coating over the surface of the board gave better protection from water absorption and thickness swell. However, it was difficult to achieve a uniform, continuous skin of oil without applying more than two coats. The coating remained on the surface of some areas and seeped into the surface strands and crevices in others. The other factor affecting formation of a continuous skin over OSB surface was the presence of surface crevices. Areas of the board that did not have a hardened skin over the top swelled noticeably more than those areas that did.

4.3 Experiment 4: Surface Texturing and Void Filling Using Fixed-Size and Expandable Microspheres

The project examined the effect of modifying OSB surface texture by applying glass microspheres of various sizes. This experiment was based on the concept of the surface-roughening effect by nodules covered in hydrophobic substances found in nature (for example, lotus leaves and the bodies of certain insects). The conclusions from this phase are summarised.

1. Practical problems were identified with spraying microspheres in a water or aqueous wax emulsion carrier, including beading and discontinuous coating distribution, maintaining an even dispersion, hydrophilic surfactants, and the limited size of microspheres that can be ejected through the spray nozzle. Distribution of microspheres over the surface was very uneven.
2. Industrial glass microspheres are prone to breakage: plastic (phenolic and heat-expanding) microspheres were also tested.
3. Low and medium doses of microspheres on OSB surfaces decreased droplet contact angles due to micro-channelling. Increasing the amount of microspheres applied increased droplet-residence time on the surface; however, there was a limit to this, as applying a fully continuous layer of microspheres to the surface resulted in instant wicking away of any water droplets placed on the surface.
4. Adding fixed-size glass or phenolic microspheres to the surface actually caused a slight increase in water absorption and thickness swell.
5. Adhering fixed-size microspheres in PF resin exacerbated water absorption and thickness swell compared to those of controls, because of the tendency of cured PF on the surface to react with water and facilitate greater thickness swelling. However, adding glass or phenolic microspheres to the PF resin slightly decreased thickness swell compared to using PF resin alone.
6. Adding glass or phenolic microspheres in linseed oil exacerbated water absorption and thickness swell compared to applying linseed oil alone. This may be due to the microspheres reducing the amount of the linseed oil barrier being applied to the surface and breaking up the continuity of the hard-setting skin.
7. The only kind of microsphere that decreased thickness swell and water absorption was the expandable kind. Applying and expanding these microspheres alone to the board surface created a dusty but strongly hydrophobic layer to water droplets. Their ability to prevent thickness swell was quite good, but the coating was easily washed off by water or rubbing, reducing its effectiveness. Effectiveness was reduced as the initial size of the expandable microspheres increased from 20 μm to 80 μm .
8. The surface-dust problem was eliminated by adding the expandable microspheres to diluted PF resin or to linseed oil. Bonding the microspheres with PF resin retained the integrity of the coating but resulted in slightly increased thickness swell compared to applying only expandable microspheres.
9. The most effective treatment was linseed oil that contained expandable microspheres. When brushed on, this treatment reduced short-term (up to 24 h) resistance of boards to thickness swell by 50% or more. Two-hour thickness swell was reduced to less than 1% compared to 2.5% for controls, whereas 24-h thickness swell was reduced to less than 8% compared with 10% for controls. The effect was relatively short-lived, due to the eventual deterioration of linseed oil by water. It was felt that Expancel (the expandable microspheres) may be a useful addition to a wider range of oil-based air or UV-cured paints and coatings that are susceptible to brittleness and macro-fracturing from the swelling stress of composite-wood substrates.

4.4 Experiment 5: Roller Coating Oriented Strand Board

4.4.1 Coating spread rates

Upon visual inspection, one pass through the roller coater appeared insufficient to adequately coat the board's entire surface evenly. This was especially the case with coatings containing expanding microspheres whereby the microspheres would visibly expand in the zones containing coating. Somewhat better coverage with most coatings was achieved after two passes; however, it took three passes to get adequate coverage of Expancel on the surface strands.

4.4.2 Ultraviolet-cured coatings

1. The two brands of UV-cured finishes tested performed very differently in their ability to restrict water absorption and thickness swell. One of the products, ACI UVO 5062G5-25, was able to reduce water absorption and thickness swell to 30%–50% less than that of controls, with the coating being more effective at lower durations of exposure to water (2 h and 6 h). The other product, Akzo-Nobel Rel-Tuff UV high-gloss topcoat, exacerbated water absorption and thickness swell to more than the background level of untreated OSB.
2. The increased efficacy of the UVO 5062G5-25 compared the very poor performance of the Rel-Tuff topcoat is likely because the UVO 5062G5-25 application resulted in a thicker layer over the surface. In addition, the Rel-Tuff topcoat product is not designed to be applied directly to board surfaces: it was not able to cure completely and may have chemically deteriorated the surface strands, making them more prone to water uptake and swelling.
3. The main mode of failure with longer exposure to water for the topcoat product was the severe and uneven swelling of the strands directly beneath the coating. The main mode of failure for the UVO 5062G5-25 was localised cracking and peeling of the coating.

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